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DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

THE TITANIFEROUS IRON ORES
IN THE UNITED STATES

THEIR COMPOSITION AND ECONOMIC VALUE

BY

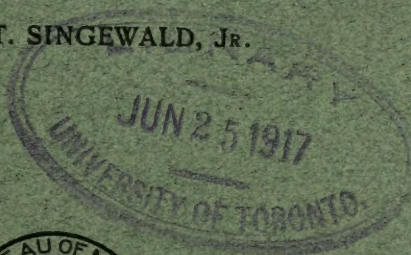
JOSEPH T. SINGEWALD, JR.

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PREFACE.

One of the problems that confronts American ironmasters is the efficient reduction of magnetite containing high percentages of titanium. From time to time the discovery of enormous bodies of workable titaniferous ore has been reported, and the available literature dealing with the geologic occurrence and the economic value of the titaniferous magnetites in the United States contains a mass of information that in part is based on incomplete observation and even on hearsay.

Although the supplies of nontitaniferous iron ore that are available in the United States are still to be measured by millions of tons, yet the approaching exhaustion of many high-grade deposits, the general acceptance by blast furnaces of ores lower in iron than those utilized 10 years ago, and the probability of even lower-grade ores being used in increasing quantities indicate that some large deposits of ore would be contributing to the needs of the country were it not for their titanium content. In an attempt to ascertain just what the economic possibilities of the larger deposits of titaniferous iron ore may be, the Bureau of Mines took up the study of the possible utilization of these ores through some concentrating process. The conduct of this investigation was assigned to Mr. J. T. Singewald, jr., and the results are presented in this report. Mr. Singewald was directed to pay especial attention to the possibility of utilizing titaniferous ores at a profit with present methods and devices and under existing conditions. He was authorized to study in detail the physical structure and chemical composition of the ores, as bearing on the problem of utilization, but not to undertake any detailed investigation of the origin and geologic distribution of the deposits.

It is to be regretted that the results of Mr. Singewald's careful study of the ores are chiefly negative. Some deposits of titaniferous iron ore are clearly not as extensive nor as high in iron as they were reported to be. Moreover, examination of many samples by metallographic methods has demonstrated that although a large part of the titanium in these ores is in the form of ilmenite, much of this ilmenite is far more intimately associated with the magnetite than has generally been supposed. Part of the magnetite and ilmenite occurs in such large and distinct aggregates that their separation by a magnetic concentration after fine crushing is practicable, but in by far

the larger number of samples examined and in practically all the ore bodies that are known to be large enough and rich enough in iron to be of much importance, most of the ilmenite occurs as such fine intergrowths in the mass of the magnetite that a complete separation of the two minerals by any process based on difference of physical properties still seems impractical. Crushing even to 200 mesh would not insure a clean separation of the two minerals. Consequently the problem of utilizing titaniferous magnetites involves the application of chemical rather than physical methods. In short, the problem is not one of eliminating the titanium by milling but of reducing the ores directly by some smelting process.

Iron ores containing over 1 per cent of titanium are troublesome to smelt in the blast furnace. Though Rossi and other investigators have demonstrated the possibility of eliminating titanium through the formation of relatively fluid slags consisting of complex titanosilicates, there seems to be no inclination on the part of the ironmasters to adopt furnace practice to these conditions. However, as Mr. Singewald points out, it is practicable to use in blast-furnace mixtures small proportions of the concentrates from a magnetic separation of the titaniferous ores with little change in present methods and without danger of choking a furnace. The use of electricity in smelting offers other possibilities. The reduction of titaniferous ores in electrically heated furnaces and the production of iron-titanium alloys by a direct process are problems of such importance that the Bureau of Mines, in connection with its investigations of the treatment of ores and of more efficient methods of smelting, is undertaking experiments with these ores. The results of these experiments will be published in future reports of the bureau.

J. A. HOLMES.

THE TITANIFEROUS IRON ORES IN THE UNITED STATES; THEIR COMPOSITION AND ECONOMIC VALUE.

By JOSEPH T. SINGEWALD, Jr.

INTRODUCTION.

The term "titaniferous magnetite" is used to designate those magnetic ores of iron that carry more than 2 or 3 per cent of titanium. Large and easily workable deposits of these ores occur in different parts of the world, and have attracted attention for many years. Under present furnace practice, however, the smelting of these ores is both difficult and expensive, and for that reason they are not accepted by furnaces, so that the deposits are practically worthless. The problem of finding a feasible method of utilizing these ores has naturally been attractive, and numerous attempts have been made to solve it.

Experiments to that end embrace two lines of investigation. The one that has been the more frequently tried is the elimination of the titanium from the ores, so as to make possible their smelting in the usual way. The other is the devising of a method of smelting by which titaniferous ores may be reduced as economically as are non-titaniferous ores. The former method involves a physical process, the latter a chemical process.

The measure of success attainable by the first method depends entirely on the relations between the iron and the titanium in the ore. Views in regard to these relations have been divergent. Some investigators have believed the titanium to occur as a part of the magnetite molecule, in which case, of course, any process of mechanical separation would be impossible. Others have believed that the titanium occurs as the mineral ilmenite, and that the ores are aggregates of magnetite and ilmenite. In this case a separation of the two minerals is theoretically possible. Magnetite is highly magnetic; ilmenite is nonmagnetic or only feebly magnetic. Crushing and magnetic concentration should separate them. Numerous experiments in magnetic separation have been made with various degrees of success, but rarely has more than a very imperfect separation been obtainable. In other words, some of the titanium exists in a separable form and some in an inseparable form, and the ratio between the two forms is

different in different ores. The whole question as to the nature of the ores remains little understood.

The use of the metallographic microscope seemed to offer a means of determining the relations that exist between the titanium and the iron in these ores. In the winter of 1911, in the capacity of Henry E. Johnston scholar at the Johns Hopkins University, the author took up the study of the problem along these lines. The necessary apparatus and laboratory facilities were provided by the geological department of the university. Material for a preliminary study was very kindly furnished by Prof. J. F. Kemp from the collection of titaniferous ores made by him and contained in the collections at Columbia University. This material was supplemented by ores obtained from Mr. W. L. Cumings, of the Bethlehem Steel Co.

A study of this material yielded results warranting a more thorough investigation of the problem, and this was made possible through the Bureau of Mines, with which the author became connected in June, 1911. The summer of 1911 was spent in visiting the principal localities in the United States at which titaniferous iron ores occur, for the purpose of making systematic collections of material. The following winter was spent in a study of the collected material in the geological laboratory of the Johns Hopkins University where the author continued as a Johnston scholar. This report is an account of the results obtained.

The author wishes to express his appreciation to those who made possible the carrying out of this investigation and to those who rendered assistance during its progress.

THE UTILIZATION OF TITANIFEROUS IRON ORES.

As stated above, the problem of the utilization of the titaniferous iron ores can be attacked along two lines—first, by the use of metallurgical processes, involving the direct reduction of the ores; second, by the use of milling methods, involving the elimination of titanium from the ores. The progress that has been made along these lines is briefly stated in the following pages.

THE SMELTING OF TITANIFEROUS IRON ORES.

SMELTING IN THE BLAST FURNACE.

Notwithstanding extensive discussions of the subject from time to time, the possibilities of smelting titaniferous iron ores in the blast furnace are still undetermined. That such ores have been smelted and excellent pig iron made from them is well known. It is equally well established that in many such cases the consumption of fuel has been so great as to make the cost of the process excessive. At present there is a prejudice, justifiable or not, against the use of ores carrying

more than 1 per cent of titanium. This prejudice is based chiefly on the belief that the ores require an undue amount of fuel to reduce them, and that they cause the accumulation of infusible titanium compounds that ultimately choke the furnace.

A historical review of the use of titaniferous iron ores shows that their use has gradually declined. In the early days of the Catalan forge and small charcoal furnaces it did not seem to make any particular difference whether an ore was titaniferous or not. Many deposits of titaniferous ores were worked and smelted without difficulty. This fact no doubt is explainable in part by the condition of the iron industry at that time. Some of the arguments that are used against the ores at present would have been of little weight in those days. The enterprises were small and the production of iron was of far greater moment than the cost of production. The early furnaces and forges were surrounded by virgin forests, and the amount of charcoal required was not considered an important factor. Later, as the furnaces increased in size and the expense of procuring charcoal became greater, the quantity of fuel required to produce a ton of iron had to be taken into consideration. As the higher the titanium content of an ore, the lower the possible iron content, the use of titaniferous ores was of itself equivalent to the use of lower-grade ores. Further, the slags produced from titaniferous ores in ordinary furnace practice are less fluid, and hence the furnace had to be run at higher temperatures. This method of operation caused the reduction of the titanium, a result that was favorable to the formation of infusible accretions of titanium in the furnace. Thus the use of titaniferous ores tended naturally to a high fuel consumption, and at times to the choking of the furnace. The prejudice against the ores became so great that finally no furnace would knowingly use them.

However, because the deposits of titaniferous ore are so numerous and so large, and the ores so low in phosphorus and sulphur, they have never ceased to attract attention and numerous experiments have been conducted looking to a means of utilizing them. During the sixties and seventies of the last century the subject was repeatedly discussed in the Journal of the British Iron and Steel Institute. Attention was called to the fact that these ores had been worked and were then being worked in a number of furnaces in Norway, Sweden, and England. At some of those furnaces the entire charge consisted of titaniferous ores, at others they were mixed with nontitaniferous ores. With the evolution of the modern blast furnace, however, all of these attempts have gradually been discontinued. A century ago there were 15 small charcoal furnaces in operation at Taberg in Sweden, but for a number of years the deposit has been wholly abandoned.

Probably the most extensively used of these ores in the United States were those of Lake Sanford, N. Y. A furnace with a daily capacity of 3 or 4 tons was built there in 1840. The furnace was subsequently enlarged, and a second furnace with a capacity of 12 to 15 tons was built. This remained in operation until 1856. The natural difficulties due to the inaccessible location of the enterprise were of themselves almost insuperable, so that its duration is rather remarkable apart from any difficulties due to the highly titaniferous character of the ores.

Two blast furnaces were erected on Bay St. Paul in 1873 by the Canadian Titanic Iron Co. to utilize the titaniferous ores of that part of the St. Lawrence region,^a but were operated for only a few years. Under the most favorable circumstances 3,040 to 3,792 pounds of charcoal per ton of iron was required, and when the ore and the limestone had become wet or covered with ice, as much as 6,400 pounds was required. Harrington states that the experience in Sweden has been that in many cases more than twice as much charcoal is necessary than is required to smelt ordinary magnetites.

In most cases it seems that no attempt was made to adapt the furnace charges to the nature of the ores. It will be interesting, therefore, to review some of the results that have been obtained when such attempts were made.

David Forbes, who was connected with charcoal ironworks in southern Norway that used titaniferous ores, states ^b that the experience of the Scandinavian ironmasters has shown that the only objection to their use is that they require a large amount of charcoal, and hence their use is not profitable where other ores free from titanium can be obtained at a reasonable rate. For this reason he found it unprofitable to smelt alone an ore carrying 42.04 per cent Fe and 15.10 per cent TiO₂, but could readily use such an ore with equal parts of a nontitaniferous ore. In the attempts to smelt it more easily, he says, his predecessor, supposing that a volatile compound of silicon and titanium would be formed, fluxed the ore with increasing charges of stamped quartz until a cast iron was obtained so highly charged with silicon that "it flowed from the furnace like porridge." Forbes went to the other extreme in fluxing with lime so as to form a titanate of lime and obtained unsatisfactory results. Subsequently he found that by using both quartz and limestone as fluxes silicotitanates of much more fusible character were formed and more satisfactory results were obtained. When the amount of titanium in the ore did not exceed 8 per cent, or was reduced to 8 per cent by admixing other

^a Harrington, B. J., Notes on the iron ores of Canada and their development; Geol. Survey of Canada, Rept. for 1873-74, pp. 249-251.

^b Forbes, David, On the composition and metallurgy of some Norwegian titaniferous iron ores; Chem. News, 1868, pp. 275-276.

ores, no difficulty was experienced in working the ore cleanly and profitably.

An attempt made by the Norwegian Titanic Iron Co. to smelt highly titaniferous ores at Norton, England, met with failure after a few years' trial. W. M. Bowron, who was connected with the company as chemist, states ^a that "the process, regarded as a process, was a perfect success; but the enormous quantity of fuel required, the small quantity of iron in the ore, and the cost and uncertainty of importation militated seriously against its commercial success." The ores used by the company were composed of 36.33 per cent Fe and 39.20 per cent TiO_2 . Nearly 3 tons of charcoal were required to produce 1 ton of iron. The smelting of such an ore is obviously not a fair test of what can be done with average titaniferous iron ores. A nontitaniferous magnetite carrying such a low percentage of iron would not be used in a blast furnace without previous concentration. The results are important in that they show the possibility of smelting even the highest titanium-bearing ores successfully, though not economically, in the blast furnace.

A very thorough study of the problem has been made in this country by Rossi. In 1890 he published ^b a review of what had been accomplished in the way of smelting titaniferous iron ores both in this country and abroad. Rossi's review, however, adds no essential facts to what has already been said. Three years later he published ^c the results of some experiments that he conducted. His experiments, made along the lines adopted by Forbes, were designed to discover easily fusible titanate slags of low viscosity. He first experimented with the formation of compounds that could be easily fused and liquefied. He then mixed ore charges to produce slags of such composition to determine whether pig iron could be made to separate from them. The results of these experiments are given in detail in the paper cited; it will be sufficient to state here that he obtained the best results with a tribasic slag, in which the bases were lime, magnesia, and alumina. The experiments were first conducted in a small furnace without forced draft; subsequently a small blast furnace was erected. The latter yielded pig iron and slags that showed good fluidity and fusibility, and there was no choking of the furnace with infusible titanium compounds. The ores experimented on ranged from 18.70 to 20.03 per cent TiO_2 .

In 1895 the experiments were repeated by Rossi ^d on a larger scale in a furnace with a daily capacity of about 3 tons, no difficulties being experienced in running the furnace. These experiments showed that

^a Bowron, W. M., The practical metallurgy of titaniferous ores: Trans. Am. Inst. Min. Eng., vol. 11, 1883, pp. 159-164.

^b Rossi, A. J., Titanium in blast furnaces: Jour. Am. Chem. Soc., vol. 12, 1890, pp. 90-117.

^c Rossi, A. J., Titaniferous ores in the blast furnace: Trans. Am. Inst. Min. Eng., vol. 21, 1893, pp. 832-864.

^d Rossi, A. J., The smelting of titaniferous ores: Iron Age, 1896, vol. 1, pp. 354-356, 464-469.

the most refractory slags could be melted without reducing silica, and hence much less titanitic acid. Under the conditions of the experiments he says that furnaces can not be troubled with titanium deposits. "The deposits consist of cyano-nitride of titanium, which supposes for its formation not only the reduction in the furnace of titanitic acid to titanium but the highest temperature and other conditions." He further says: "It may be argued that circumstances may so occur in the running of a blast furnace smelting any kind of nontitaniferous ores that would lead to an obstruction whose removal would require forcing the heat and the pressure of the blast, and that these circumstances in the special case of titaniferous ores would be favorable to the formation of titanium deposits by the reduction of the titanitic acid." His reply to this is that the action of the blast furnace is so well understood and in such competent hands at the present time that such conditions are very rare; but if they should arise, it would be easy to change the charge to nontitaniferous ores until the obstruction has been removed and the furnace brought back to normal condition.

In order to become familiar with the behavior of his furnace under normal charges, it was first run for a time on Lake Superior ores; these were then gradually replaced by titaniferous ores and the flux changed from calcite to a dolomite carrying 12 to 14 per cent of magnesia. The titaniferous ores consisted of four-fifths to five-sixths Sanford or Millpond ore and one-fifth to one-sixth Cheney Pond ore. Rossi's account of the results is given below:

In order to judge the relative economy of these three runs under as nearly as possible similar conditions, we will compare the amounts of fuel and stone required per unit of pig metal when the furnace gave the greatest production in each case. This supposes, indeed, for the kind of ores or mixtures of ores considered, the most favorable conditions of running for each. By making precisely the same ample allowance of time in each case for stone and coke before each maximum cast of 24 hours as chargeable to that cast, we found the figures given below:

Results of Rossi's blast-furnace tests of different ores, based on unit quantity of pig iron when greatest production was obtained.

RUN NO. 1 WITH NONTITANIFEROUS HEMATITES FROM LAKE SUPERIOR.

Stone, unit quantity required.....	1.15
Coke, unit quantity required.....	2.15
Fe in ores, per cent.....	62
Maximum cast of iron in 24 hours, pounds.....	4,600

RUN NO. 2 WITH MIXTURE OF HEMATITE AND TITANIFEROUS ORES.

Stone, unit quantity required.....	1.19
Coke, unit quantity required.....	2.20
Fe in ores, per cent.....	56
Maximum cast of iron in 24 hours, pounds.....	5,035

RUN NO. 3 WITH TITANIFEROUS ORES FROM THE ADIRONDACKS.

Stone, unit quantity required.....	0.95
Coke, unit quantity required.....	1.99
Fe in ores, per cent.....	52
TiO ₂ in ores, per cent.....	20
Maximum cast of iron in 24 hours, pounds.....	6,735

Hence, to say the least, the titaniferous ores, under the same conditions of furnace running, did not require any more fuel per unit of pig metal than excellent non-titaniferous ores. Really they required decidedly less, and the production of the furnace was increased considerably.

Summing up the results of his experiments, Rossi concludes:

1. As anybody who may desire to make the experiment can verify, titanitic acid can form definite compounds, perfectly fusible, if properly fluxed, containing as much as 35 to 40 to 50 per cent of titanitic acid, with alumina, lime, and magnesia as bases, and admissible as slags in blast-furnace work. Larger percentages still, such as 65 per cent, can enter into a compound and it remains fusible. The objections to the smelting of titaniferous ores on account of the refractory character of the slags are not sustained by our practice or that of others, or by direct experiments on the properties of these compounds.

2. In running a furnace under special conditions of temperature and pressure of blast no troubles have been experienced from the titanium deposits. We never observed any in our blast-furnace tests, and none are mentioned by Dr. Forbes in his practice in England and Norway.

3. If these special conditions of lower heat, considered more favorable in smelting these ores, are held to imply against them a waste of fuel, it is a question whether this is not offset by the smaller amount of cinder to melt, the lesser quantity of fluxes necessary and their indirect effect upon the productive capacity of the furnace, as well as the greater value of the pig metal obtained for specific and numerous applications. This is without taking into account the possibility of not submitting to it by a rapid driving and forcing the production, conditions which, to judge from our tests, could be easily realized with these ores.

However conclusive Rossi's experiments may appear, no attempts have been made to carry them out on a commercial scale; and the titaniferous ores remain in hopeless disrepute so far as their use in the ordinary blast furnace is concerned.

SMELTING IN THE ELECTRIC FURNACE.

Electric smelting of iron ores is still in its infancy, and its full possibilities have not yet been demonstrated. Where conditions are favorable it has met with considerable success. Electric smelting is of special interest in this connection since there is a confident feeling in many quarters that herein lies the hope of the utilization of the titaniferous ores. However, our knowledge in this regard has not yet reached the point where any very definite conclusions can be drawn.

Experiments in the electrical reduction of titaniferous iron ores have been conducted in Canada. About seven years ago, Haanel^a carried out a series of experiments for the Canadian Government at Sault Ste. Marie in the smelting of Canadian iron ores by the electrothermic process, titaniferous iron ores being used in one of the experiments. Unfortunately this run, which was the last one made, was not as complete as the others. The furnace lining was in very bad condition, but as the time for making the experiments had nearly expired it could not be repaired and the run had to be stopped before figures as to output had been obtained. The ore used contained 17.82 per cent TiO_2 , and the furnace charge consisted of 400 pounds of ore, 100 pounds of charcoal, 50 pounds of limestone, and 50 pounds of fluorspar. The slag produced was very fluid, and the statement is made that "likely the fluorspar in the charge could have been reduced considerably or omitted altogether."^b

Abstracts from an article on this subject, recently published by Stansfield,^c who has experimented along these lines, are quoted below:

Although the possibility of the electric smelting of iron ores for pig iron can not be definitely settled in a general way, there appears to be every probability that a process which yields steel instead of pig iron would be commercially possible in favorable localities. Steel could be made by smelting titaniferous iron ores in an electric furnace with a somewhat smaller amount of charcoal than would be needed for making pig iron, and the resulting metal could be transferred in the molten condition to an electrical steel-refining furnace, where it could be made into finished steel. The cost of producing the crude steel from the ore would be little more than that of producing pig iron, and the cost of refining the steel would be only a moderate addition to this, while the price obtainable for the finished product would be decidedly higher than could be obtained for pig iron.

The writer has been associated with Mr. J. W. Evans in the development of a process in which the reduction of titaniferous ores to metal and the subsequent refining of the steel is carried out in a single furnace, and while the details of the furnace construction and certain parts of the operation have not yet been fully worked out the results have been so encouraging that it appears to be worth while to develop the process on a small working scale. With regard to the results so far obtained, it may be stated that titaniferous ores obtained from the Orton mine and containing about 7 per cent of titanium have been smelted directly to steel, and that such steel, containing about 1 per cent of carbon, has been found to possess unusually good qualities as a tool steel. The cost of smelting these ores and refining the steel can be determined fairly accurately from the figures published in regard to the electrical smelting of iron ores to pig iron and the electrical refining of molten steel. These figures are more dependable than data obtained from the small-scale experiments that have so far been made. The writer intends, however, in the near future to

^a Haanel, Eugene, Report on the experiments made at Sault Ste. Marie, Ontario, under Government auspices in the smelting of Canadian iron ores by the electrothermic process: Canada Dept. of Mines, Mines Branch, 1907, pp. 85-86.

^b Haanel, Eugene, Preliminary report on the experiments made at Sault Ste. Marie, Ontario, under Government auspices in the smelting of Canadian iron ores by the electrothermic process: Canada Dept. of Mines, Mines Branch, 1906, p. 19.

^c Stansfield, Alfred, Electric smelting of titaniferous ores: Can. Min. Jour., vol. 33, 1912, pp. 448-449.

make further experiments on the reduction and refining of the steel in order to obtain direct information as to the cost of the process.

There does not appear to be any definite limit as regards the percentage of titanium in ores suitable for this process, but the cost of smelting will, of course, increase with the proportion of titanium, both on account of the cost of fluxing it and on account of the smaller proportion of steel obtained. It seems probable, therefore, that the process will be applied to ores that do not contain more than 5 to 10 per cent of titanium. Ores somewhat richer than this in titanium may be concentrated magnetically, so as to obtain a product which shall be at once richer in iron and poorer in titanium, and it may even be possible in some cases that the tailings from such a concentration process may be sufficiently rich in titanium to be smelted for ferrotitanium. Some ores containing too much titanium for steel making are not amenable to magnetic concentration, and these may be smelted with suitable admixture of nontitaniferous ores. It has been found that the electric furnace is more suitable than the blast furnace for the treatment of pulverized ores and that magnetic concentrates can be smelted alone or with the addition of a moderate proportion of coarser ore.

The use of titaniferous ores for making tool steel would appear to be very advantageous commercially, but can not be expected to provide for a large consumption of these ores, and it is of interest to consider whether the process can be applied to the production of steel on a larger scale. One purpose for which this process would appear to be very suitable is for the production of steel castings. A good deal of difficulty is experienced in the production of steel castings which can be relied upon as being entirely sound, and ferrotitanium is used in some cases for producing soundness in steel castings. It seems very probable, therefore, that steel made directly from titaniferous ores will be particularly suitable for the production of steel castings, and this will afford a larger field for the electric smelting of these ores. With regard to the use of this process on a still larger scale—for the production of steel rails, for example—the writer would say that there appears to be no definite reason why rails should not be made by this process, but would not care to speak definitely with regard to this until the process has been in operation on a working scale.

At least there has been opened a new field of investigation, in which the solution of the problem of the utilization of the titaniferous iron ores may be found.

ELIMINATION OF TITANIUM BY MAGNETIC CONCENTRATION.

The fact that many titaniferous magnetites are granular aggregates of magnetite and ilmenite is quite apparent to the naked eye in many of the coarser-grained ores. The highly lustrous rougher surface of the ilmenite can be easily distinguished from the duller black cleavage faces of the magnetite. This difference is brought out more plainly if the specimen is immersed for a time in concentrated hydrochloric acid, which acts on the magnetite but does not affect the ilmenite. The magnetite becomes still duller and pitted as a result of the solvent action of the acid, whereas the ilmenite remains unchanged. The relations between the magnetite and the ilmenite grains are brought out still more clearly if the specimen is ground down to a plane surface, polished, and treated with hydrochloric acid.

The polished ilmenite grains retain their luster, whereas the polished magnetite loses its luster and assumes a dull black. Specimens of ore that have been treated in this way are shown in Plate II, *B*, *C*, *D*, *E*, and *F* (p. 50), Plate VIII, *B* (p. 106), and Plate IX, *B* (p. 110).

Newland^a applied this treatment to some of the Adirondack ores. Commenting on the results obtained, he says:

In the specimens that have been examined the magnetite and ilmenite are distinguishable without difficulty. There is a clear separation of the particles and no notable tendency toward intergrowth or inclusion on the part of either. The boundaries are sharp. Both minerals belong to the same order of crystallization, though the ilmenite seems to have begun to form somewhat earlier than the magnetite. The latter being commonly in excess constitutes the groundmass through which the ilmenite is more or less regularly distributed in grains of fairly even size.

A great many of the bright ilmenite grains have been isolated and tested with a magnet, and in every case were found to be practically nonmagnetic. Dull grains of magnetite similarly tested have in every case been found to be highly magnetic. Further the specimens mentioned above bear out Newland's statement that there is "no notable tendency toward intergrowth or inclusion on the part of either." Although there are numerous small grains of ilmenite scattered over the surface of the magnetite, they form an insignificant part of the total visible ilmenite; and nearly all of the ilmenite grains in the coarse granular ores are of sufficient size to be separated from the magnetite by crushing to a size allowable in actual commercial operations. If all of the titanium in titaniferous magnetites were contained in these ilmenite grains, magnetic concentration ought to give concentrates practically free from titanium. Some results that have actually been obtained in attempting to make a magnetic separation of the titanium are presented below:

RESULTS OF MAGNETIC-SEPARATION EXPERIMENTS.

The results of magnetic separations of foreign titaniferous magnetites are tabulated first; these are followed by a tabulation of the results of separations of ores from the United States. The latter results are also discussed subsequently. Pope^b made three tests of ores from eastern Ontario. The experiments were made with a Wetherell magnetic concentrator at Newark, N. J. The ore was crushed so that it would pass through a 40-mesh screen but not through a 60-mesh screen.

No separation of Eagle Lake ore was possible. As soon as the current was strong enough to pick up a single particle all were picked up. This ore analyzed 64.68 per cent Fe and 6.41 per cent TiO_2 .

^a Newland, D. H., *Geology of the Adirondack magnetic iron ores*: N. Y. State Mus. Bull. 119, 1903, pp. 151-152.

^b Pope, F. J., *Investigation of magnetic iron ores from eastern Ontario*: Trans. Am. Inst. Min. Eng., vol. 29, 1899, pp. 372-405.

The results with Pine Lake ore are tabulated below:

Results of magnetic concentration of Pine Lake ore.

	Current.	Weight.	Fe.	TiO ₂ .
		<i>Grams.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Ore.....	Single dry cell.....	380	43.38	13.52
Heads.....		272	56.45	18.10
Tails.....				

The result of the concentration was to increase the metallic iron by ten thirty-thirds and the titanic oxide by eleven thirty-thirds.

The results with Chaffey ore were as follows:

Results of magnetic concentration of Chaffey ore.

	Current.	Weight.	Fe.	TiO ₂ .
		<i>Grams.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Ore.....	<i>Amperes.</i> 0.25.....	720	53.0	7.4
Heads.....		640	56.1	5.0
Tails.....		73	27.0	29.9

Here the iron was increased 6 per cent and the titanium reduced 32 per cent by the concentration.

The results of many magnetic concentrations, principally of Norwegian ores, have been tabulated by Vogt,^a as shown below:

Results of magnetic concentration of titaniferous iron ores from Heindalen.

Test designation.	Composition of ore.	Yield of concentrate.	Composition of concentrate.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
b.....	7.08 TiO₂..... 44.66 Fe..... 0.95 S..... 0.013 P.....	49.02	1.49 TiO₂..... 68.51 Fe..... 0.097 S..... 0.006 P.....
b c.....	6.20 TiO₂..... 35.85 Fe..... 0.023 P.....		1.30 TiO₂..... 67.73 Fe..... 0.004 P.....
c c.....	4.90 TiO₂..... 27.65 Fe..... 0.042 P.....	23.98	0.72 TiO₂..... 69.90 Fe..... 0.003 P.....

^a Vogt, J. H. L., Norges Jernmalforekomster: Norges Geologiske Undersokelse 51, 1910, pp. 31-34.
A German review by Vogt is contained in the Zeitschr. prakt. Geol., 1910, pp. 62-64.

^b Represents a large-scale test made by a company in Stockholm.

^c Represents laboratory test made by Prof. Henry Louis.

Results of magnetic-concentration tests by Farup.

Test designation.	Composition of ore.	Effects of crushing ore to 1 mm.		Effects of crushing ore to 0.1 mm.	
		Yield of concentrate.	Composition of concentrate.	Yield of concentrate.	Composition of concentrate.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
A.....	7.15 TiO ₂ 35.07 Fe.....	46.51		34.97	0.40 TiO ₂ 69.60 Fe.....
B.....	8.48 TiO ₂ 42.61 Fe.....				0.96 TiO ₂ 68.40 Fe.....
C1.....	4.32 TiO ₂ 21.33 Fe.....	28.01		20.92	1.03 TiO ₂ 66.34 Fe.....
C2.....	6.60 TiO ₂				1.22 TiO ₂ 67.59 Fe.....
C3.....	6.30 TiO ₂	58.82	2.65 TiO ₂	42.02	1.16 TiO ₂ 67.59 Fe.....
C4.....	7.21 TiO ₂	50.50	4.23 TiO ₂	36.63	1.47 TiO ₂ 67.4 Fe.....
C5.....	6.81 TiO ₂	64.10	3.33 TiO ₂	47.62	1.53 TiO ₂ 65.68 Fe.....
D1.....	9.03 TiO ₂ 49.3 Fe.....	75.19	5.00 TiO ₂ 62.24 Fe.....	63.29	1.24 TiO ₂ 68.82 Fe.....
	0.81 S..... 0.017 P.....				
D2.....	8.21 TiO ₂ 46.44 Fe.....	60.60		50.25	1.20 TiO ₂ 68.70 Fe.....
	1.02 S..... 0.014 P.....				
D3.....	7.80 TiO ₂ 51.20 Fe.....	69.93	4.09 TiO ₂ 61.38 Fe.....	63.69	2.35 TiO ₂ 64.59 Fe.....
E.....	5.48 TiO ₂ 62.0 Fe.....				
F.....	32.9 TiO ₂ 45 Fe ^a	24.39	4.27 TiO ₂ 63.65 Fe.....	19.23	1.60 TiO ₂ 69.65 Fe.....
G.....	15.04 TiO ₂ 50 Fe ^a				
H.....	13.55 TiO ₂ 40 Fe ^a	65.36	10.01 TiO ₂ 47.34 Fe.....	47.85	1.75 TiO ₂ 68.1 Fe.....
I1.....	13.49 TiO ₂ 50 Fe ^a				
I2.....	10.87 TiO ₂ 50 Fe ^a	81.97		53.48	2.37 TiO ₂ 68.60 Fe.....
K.....	14.10 TiO ₂				
L.....	7.78 TiO ₂ 49.52 Fe.....	76.92	14.52 TiO ₂ 53.72 Fe.....	41.67	4.81 TiO ₂ 60.99 Fe.....
M.....	9.80 TiO ₂ 41.2 Fe.....				
		71.43	12.98 TiO ₂	62.89	10.80 TiO ₂

^a Approximate.

Tests A, B, C, etc., represent ores from different deposits; C1, C2, C3, etc., represent ores from different places in the same deposit. A, B, and C represent ores from Heindalen, D from Rödssand, F from Laxedal in the Ekersund-Soggendal district, G from Solnor, and I from Lied. The sources of the others are not given.

Commenting on the results of these tests, Vogt says that "the so-called titanomagnetite in these tests consists of a mechanical mixture of magnetite and ilmenite. Whether the magnetite contains a small amount of TiO₂ in chemical combination is an open question. It is not probable, however, as the investigations show that the finer the crushing, the greater the quantity of titanitic acid removed." In the cases of tests G, H, and I he regards the intergrowth to have been somewhat finer than in tests A, B, C, and D; and in K, L, and M he considers that much of the intergrowth was of microscopic size. Whether at the time of the solidification of the magmas primary

magnetite and primary ilmenite crystallized, or whether at that time a magnetite formed that at high temperature contained ilmenite in solid solution, the ilmenite subsequently segregating at lower temperatures, he says can not yet be decided.

In addition to the above tests, Vogt gives the results of several tests made on magnetic sands. The results of one of these are presented below:

Results of magnetic-concentration tests of magnetic sand from Lofoten Islands, Norway.

[Size of sand grains—73.3 per cent less than one-quarter mm. but greater than one-sixth mm.; 26.7 per cent less than one-sixth mm.]

Determined constituents of sand.	Amount.	Condition of sand.					
		Not crushed.		Crushed to less than $\frac{1}{8}$ mm.		Powdered.	
		Concentrate.	Tailings.	Concentrate.	Tailings.	Concentrate.	Tailings.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	
TiO ₂	13.20	5.03	26.90	3.14	26.7	2.5	.....
Fe.....	56.55	67.70	43.56	69.24	43.59	70.33	.....
P.....	.06	.045	.....	.026	.....	.....	.....
S.....	.007	.002	.....	.002	.....	.....	.....
SiO ₂	3.52	.85	.....	.250	.....	.....	.....
Percentage of whole.....		53.8	46.2	50.5	49.5	47.7	52.3

The tests were made by a company in Stockholm, Sweden, as were also the first two in the table following. The third was made under the direction of Prof. Vogt with a Gröndal separator No. 5. Concentrate 1 was made without crushing the sand. This concentrate was then crushed to one-sixth mm. and a second separation made from it.

Results of magnetic-concentration tests of sands from lower St. Lawrence, Canada.

Quality of sand.	Composition of sand.	Amount of concentrate 1 obtained.	Composition of concentrate 1.	Amount of concentrate 2 obtained from 1.	Composition of concentrate 2.	Composition of tailings 2.
		<i>Per cent.</i>		<i>Per cent.</i>		
Lean.....	{ 3.7 TiO ₂ 18.6 Fe..... }	10.9	{ 4.4 TiO ₂ 65.6 Fe..... }	89.4	{ 2.9 TiO ₂ 69.8 Fe..... }	30.1 Fe.
Rich.....	{ 18.6 TiO ₂ 54.8 Fe..... }	42.2	{ 2.3 TiO ₂ 69.6 Fe..... }	96.6	{ 1.5 TiO ₂ 70.5 Fe..... }	44 Fe.
.....	{ 7.9 TiO ₂ 29.4 Fe..... }	26.5	{ 3.9 TiO ₂ 66.3 Fe..... }	95	{ 2.0 TiO ₂ 69.6 Fe..... }	37 Fe.

The results of magnetic concentrations of titaniferous iron ores of the United States are presented below. They are a tabulated summary of the results discussed in a subsequent section of this report. The first table gives the results of tests previously made and the second of tests made by the author in the course of this investigation.

In the author's tests small samples of ore were crushed in a diamond mortar to pass through a 50-mesh screen having an opening of 0.3 mm. The crushed material was sorted into two sizes with a 100-mesh screen having an opening of 0.15 mm. Each size was then subjected to magnetic separation under water with a hand magnet. The resulting concentrates and tailings were analyzed for Fe and Ti by A. C. Fieldner, of the Bureau of Mines. The composition of the original ore was calculated from the ratio of concentrates to tailings.

Results of magnetic separations previously made.

Source of ore.	Size of screen passed through.	Determined constituents of ore.		Determined constituents of concentrate.		Determined constituents of tailings.	
		TiO ₂ .	Fe.	TiO ₂ .	Fe.	TiO ₂ .	Fe.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Sanford, N. Y.				4.00	62.66	47.50	38.86
Do.	40-mesh.	14.0	60.58	8.93	60.43	45.23	45.78
Do.				9.66	60.60	32.22	42.84
Do.	16-mesh.			5.25	63.00		
Do.	40-mesh.			^b 5.90	^b 65.02		
Do.				11.00	61.04		
Tuscarora, N. C.		15.35	41.95	1.27	67.60	16.20	21.63

^a From concentrate of ore mentioned just above.

^b Average of two analyses.

Results of magnetic separations made by the author.

Source of ore.	Determined constituents of ore.		Effect of crushing ore to 0.3 mm.				Effect of crushing ore to 0.15 mm.			
			Yield of concentrate.	Determined constituents of concentrate.		Determined constituents of tailings.		Yield of concentrate.	Determined constituents of concentrate.	
	TiO ₂ .	Fe.		TiO ₂ .	Fe.	TiO ₂ .	Fe.		TiO ₂ .	Fe.
	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
Lincoln Pond, N. Y.	5.88	64.66	96.0	4.82	66.08	31.45	30.59	95.6	5.12	66.27
Sanford, N. Y.	19.02	55.07	78.2	11.15	61.23	47.20	32.99	75.9	10.47	61.23
Millpond, N. Y.	18.02	54.47	83.2	13.18	58.89	43.03	32.74	85.3	12.28	59.17
Tuscarora, N. C.	12.82	58.07	71.5	4.25	67.76	34.32	33.76	70.1	3.64	68.41
Iron Lake, Minn.	24.30	53.30	93.3	23.15	54.93	40.37	30.59	92.0	23.58	54.13
Iron Mountain, Wyo.	21.75	52.31	84.2	18.30	56.75	40.12	28.74	83.6	17.25	56.75
Do.	19.47	54.48	77.7	12.58	60.76	43.47	32.61	76.0	10.32	61.97
Do.	21.85	51.93	87.3	20.03	55.35	34.33	28.43	86.5	30.03	55.44
Shanton Ranch, Wyo.	21.08	51.50	84.7	17.85	55.05	38.93	31.83	82.2	17.85	55.63
Do.	19.98	52.98	84.1	17.22	56.93	34.58	31.96	78.6	16.72	57.30
Iron Mountain, Colo.	14.50	51.96	86.0	13.50	56.93	20.97	21.42	80.4	13.10	57.77

The table following is compiled from the two preceding tables. It gives the amount of titanium per unit of iron in the ore and in the concentrates, and where known the size to which the ore had been crushed. From these ratios the percentage reduction of titanium per unit of iron is calculated. It is recognized that the results of such a calculation are not strictly comparable. The percentage of iron given by analysis is the total iron content. Some of this iron is present in the iron-bearing minerals of the gangue, and is not asso-

ciated with the titanium, and these minerals are practically removed from the concentrates. The ratio of titanium to iron in the concentrates is therefore the ratio of the titanium to the iron with which it is actually associated, whereas the ratio of titanium to iron in the ore is the ratio of the titanium to the iron with which it is associated plus the iron contained in the gangue minerals. The iron contained in the gangue is removed in the magnetic concentration of ordinary magnetic ores, and this process does not bear on the problem of eliminating titanium from titaniferous magnetite. The presence of iron in the gangue lowers the calculated ratio of titanium to iron in the ore, and hence the calculated percentage of titanium removed per unit of iron is less than is actually the case. The leaner the ore the greater the discrepancy. For this reason, the percentage of iron present in the crude ore is included in the table.

Summary of results of magnetic separations.

FOREIGN ORES.

Source of ore.	Ore.		Concentrate.		
	Fe.	Ti per unit Fe.	Maximum size of grain.	Ti per unit Fe.	Reduction of Ti per unit Fe.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Mm.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Eagle Lake.....	64.68	0.0595	a 0.3	0.0595	0
Pine Lake.....	43.38	.1870	a .3	.1924	b 3
Chaffey.....	53.0	.0838	a .3	.0537	36
Heindalen a.....	44.66	.0951	.....	.0130	86
Heindalen b.....	35.85	.1038	.....	.0115	89
Heindalen c.....	27.65	.1063	.....	.0062	94
Heindalen A.....	35.07	.1223	.1	.0035	97
Heindalen B.....	42.61	.1194	.1	.0084	93
Heindalen C1.....	21.33	.1215	.1	.0093	92
Rödsand D1.....	49.3	.1099	.1	.0103	90
Rödsand D2.....	46.44	.1061	.1	.0105	90
Rödsand D3.....	51.20	.0914	.1	.0218	76
E.....	62.0	.0530	.1	.0138	74
Iaxedal F.....	a 45	.4387	.1	.0154	96
G.....	a 50	.1805	.1	.0207	89
H1.....	a 40	.2032	.1	.0473	77
I1.....	a 50	.1619	.1	.0636	61
I2.....	a 50	.1304	.1	.0710	46
L.....	49.52	.0943	.1	.0829	12
Lofoten.....	56.55	.1401	.2	.0272	81
St. Lawrence (lean).....	18.6	.2161	.2	.0249	89
St. Lawrence (rich).....	54.8	.2036	.2	.0128	94
St. Lawrence.....	29.4	.1612	.2	.0172	89

UNITED STATES ORES.

Sanford.....	60.58	0.1388	a 0.3	0.0886	36
Tuscarora.....	41.95	.2195	.....	.0113	95
Lincoln Pond.....	64.66	.0546	.15	.0464	15
Sanford.....	55.07	.2072	.15	.1026	50
Millpond.....	54.47	.2005	.15	.1245	38
Tuscarora.....	58.07	.1324	.15	.0319	76
Iron Lake.....	53.30	.2735	.15	.2614	5
Iron Mountain, Wyo.....	52.31	.2495	.15	.1824	27
Do.....	54.48	.2144	.15	.0999	53
Do.....	51.93	.2544	.15	.2163	15
Shanton.....	51.50	.2456	.15	.1925	22
Do.....	52.98	.2263	.15	.1750	23
Iron Mountain, Colo.....	51.96	.1674	.15	.1361	18

a Approximate.

b Increase.

The results of magnetic concentrations just cited show that the relations between the iron and the titanium in the titaniferous magnetites are not as simple as a megascopic examination of the ores would indicate. It is evident that a large part of the titanium is contained in the magnetite itself. The variation in the degree of separation obtained in the different cases shows further that the percentage of ilmenite in separable form and that present in inseparable form is not constant, but varies over a wide range. The only advantage to be derived from magnetic concentration of these ores, in so far as the titanium is concerned, is that in some cases the percentage of titanium can be brought low enough to make practicable the mixing of the concentrates with two, three, or four parts of non-titaniferous ores, whereby the titanium content would be made negligible.

MICROSTRUCTURE OF TITANIFEROUS MAGNETITE.

PREVIOUS INVESTIGATIONS.

It has been shown that in most titaniferous magnetites that have been subjected to magnetic concentration a large percentage of the titanium occurs in the magnetite in a form not separable from the magnetite by that process and not visible to the naked eye. That seemingly homogeneous magnetite crystals can contain a high percentage of titanium has been recognized for many years, and the manner in which it occurs in the magnetite has been the subject of considerable speculation. Fifty years ago Knop^a analyzed some magnetite octahedra from Meiches in the Vogelsberg, and found 24.95 per cent of TiO_2 ; and Kemp^b says that O. A. Derby has mentioned to him the occurrence of natural loadstone in Brazil with 20 per cent of TiO_2 . A sample of seemingly pure magnetite picked from a specimen of Lake Sanford ore contained 11 per cent of TiO_2 .^c

In 1858 Rammelsberg^d expressed the view that the titanium-bearing magnetites consist of mixtures of titanium-free octahedral magnetite and rhombohedral ilmenite. Since that time a number of workers have recognized microscopic intergrowths of magnetite in ilmenite.

Though the intergrowths of ilmenite and magnetite are far more common, intergrowths of rutile and magnetite were discovered about the same time. Thus in 1877 Seligmann^e described regular intergrowths of rutile in magnetite crystals from the Alp Lercheltiny in

^a Knop, A., Ueber titansaure haltigen Magneteisenstein: Liebigs Ann. chem. pharm., vol. 123, 1862, p. 352.

^b Kemp, J. F., The titaniferous iron ores of the Adirondacks: U. S. Geol. Survey 19th Ann. Rept., pt. 3, 1899, p. 386.

^c See p. 76.

^d Rammelsberg, C., Ueber die Zusammensetzung des Titaneisens, sowie der rhomboëdrisch und oktaëdrisch Krystallisirten Eisenoxyde überhaupt: Pogg. Ann., vol. 104, 1858, pp. 497-552.

^e Seligmann, G., Mineralogische Notizen: Groth Zeitschr. für Kryst. und Min., vol. 1, 1877, pp. 340-342.

Binnenthal, Switzerland. About the time that the microscopic intergrowths of magnetite in ilmenite were first discovered Cathrein^a described a regular microscopic intergrowth of rutile in magnetite analogous to the macroscopic intergrowth described by Seligmann. He found that on dissolving the magnetite in hydrochloric acid there was left behind an aggregate of minute rutile microlites arranged parallel to the three edges of an octahedral face and intersecting each other at an angle of 60°. The magnetite itself appeared black and opaque, wholly homogeneous, and even great magnification failed to reveal the intergrown rutile.

Neef,^b describing a diabase, says:

Accessory constituents are pyrite and a black ore showing on the surface of the section distinct systems of lines cutting each other at acute angles which seem to indicate intergrowths of ilmenite-lamellæ. On etching the section with hot hydrochloric acid the ore readily dissolved, leaving behind an undecomposed latticework skeleton of ilmenite. Is this perhaps an intergrowth of specularite or magnetite with ilmenite lamellæ cutting each other at acute angles?

The same observation was made by Küch^c a few years later in studying some West African rocks. He says in the description of a plagioclase-olivine-augite rock:

On treating a thin section with hydrochloric acid the magnetite goes into solution. There remains behind, however, a latticework skeleton formed of laths which must be ilmenite, and which as such are lacking in the unetched section. This relation seems to point to intergrowths of ilmenite and magnetite, the latter being dissolved through the treatment with acid, so that only the ilmenite lamellæ remain. The same phenomenon has already been observed by Neef in a Swedish diabase.

About the same time a similar conclusion was reached by Teall^d from a somewhat different consideration. His article was read in June, 1884, but refers to the one by Küch just quoted. He found an opaque iron oxide which carried considerable TiO_2 and was yet attracted by a weak bar magnet. The analysis and the physical properties of the substance, he believed, agreed with the assumption of a mixture of magnetite and ilmenite. To corroborate such an assumption he refers to the work previously cited, and to the fact that in the whin sill the substance alters into leucoxene along two sets of parallel planes. He concludes, therefore, that an intergrowth of magnetite and ilmenite actually exists.

The first mention of a microscopic intergrowth of magnetite and ilmenite was made by Becke^e in 1886. He found that spheres of

^a Cathrein, A., Ueber die mikroskopische Verwachsung von Magneteisen mit Titanit und Rutil: *Groth Zeitschr. für Kryst. und Min.*, vol. 8, 1884, pp. 321-329.

^b Neef, M., Ueber seltene krystallinische Diluvialgeschiebe der Mark: *Zeitschr. Deutsch. geol. Gesell.*, vol. 34, 1882, p. 470.

^c Küch, R., Beitrag zur Petrographie des westafrikanischen schiefergebirges: *Tschermak's Min. Pet. Mitt.*, vol. 6, 1885, p. 129.

^d Teall, J. J. H., On the chemical and microscopic characters of the whin sill: *Quar. Jour. Geol. Soc. of London*, vol. 40, 1884, p. 657.

^e Becke, F., Aetzversuche an Mineralen der Magnetitgruppe: *Tschermak's Min. Pet. Mitt.*, vol. 7, 1886, pp. 232-233.

magnetite produced from octahedra from Pfitsch, Tyrol, Austria, were not homogeneous, but filled with tablets of ilmenite which were intercalated in the magnetite parallel to the octahedral faces. A year later Cathrein^a described the same phenomenon more fully in the case of magnetite crystals from the Zillerthal, Tyrol, Austria. He found scattered over the octahedral faces of the magnetite small laths, 1 to 2 mm. long and 0.5 mm. wide, which on closer examination proved to be the edges of black metallic tablets. Chemical investigation showed that the magnetite itself was wholly free from titanium and that the tabular inclusions were ilmenite. A study of the orientation of the tabular crystals of ilmenite within the magnetite showed that the basal plane of the ilmenite lay parallel to the octahedral face of the magnetite; that is, the position assumed was that in which similar axes of symmetry lay parallel.

In 1892, Rosenbusch^b stated that Latermann communicated to him the finding of ilmenite intergrowths in the magnetite of the nepheline basalt of the Katzenbuckel, near Heidelberg, Germany. If the magnetite in the thin section were dissolved in hydrochloric acid, there remained a network of ilmenite lamellæ which in sections parallel to the faces of (111) cut each other at an angle of 60° and in sections parallel to the faces of (001) at 90°.

Adams^c observed two distinct iron ores in the ore particles of the anorthosite of the Morin district, in Canada, on examining thin sections in reflected light. One specimen he describes as having a streaked appearance, due to the fact that one mineral cut the other in a simple or double group of broken laths. On treating the microscope slide with hydrochloric acid the one mineral dissolved, but the laths remained, showing an intergrowth of magnetite with ilmenite, or at least, he says, with a titaniferous iron ore.

In an augite mica diorite from the island of Cabo Frio, Rosenbusch^d found particles of titaniferous magnetite, which on treatment with hydrochloric acid left behind a network of brownish specular ilmenite.

Lacroix^e ascribes the titanium content of titaniferous magnetite both to intergrowths of ilmenite and magnetite and to the presence of titanomagnetite. In intergrowths of ilmenite and magnetite the tabular crystals of ilmenite are distributed in the crystals of magnetite parallel to the octahedral face, so that the two minerals have a common ternary axis. The manner of intergrowth is the

^a Cathrein, A., *Verwachsung von Ilmenit mit Magnetit*: *Groth Zeitschr. für Kryst. und Min.*, vol. 12, 1887, pp. 40-46.

^b Rosenbusch, H., *Mikroskopische Physiographie der petrographischen wichtigen Mineralien*, 1892 p. 287.

^c Adams, F. D., *Ueber das Norian oder Ober-Laurentian von Canada*: *Neues Jahrb. Min., Geol., Paleon.*, 1893, B. B. 8, p. 445.

^d Rosenbusch, H., *Mikroskopische Physiographie der massigen Gesteine*, 1896, p. 246.

^e Lacroix, A., *Minéralogie de la France et de ces Colonies*, vol. 3, 1901-1909, pp. 287-288.

same as that in the case of hematite and magnetite. He says: "It is very probable that many titaniferous magnetites owe their titanium content to similar groupings of a physical nature and are consequently different from titanomagnetite." Titanomagnetite^a he calls magnetite in which a small part of the ferric oxide has been replaced by Ti_2O_3 .

The intergrowths of ilmenite and rutile in magnetite are briefly described by Mügge,^b who, however, adds nothing to what has been stated above. The chief interest of Mügge's paper is that it discusses at some length the physical and chemical laws governing regular intergrowths of different minerals.

All of the information in regard to the intergrowths of titanium minerals in the magnetite of titaniferous magnetites that had been obtained up to this time came in the course of mineralogical and petrographic studies. No effort had been made to apply the method of attack pointed out by these results to a study of the titaniferous ores themselves. The first investigation of such a character was carried out by Hussak^c on some Brazilian titaniferous magnetites. Hussak investigated titaniferous magnetite derived both from stringers and veinlets in acidic rocks and from magmatic segregations in basic rocks. Polished plane surfaces of the ores were prepared and etched with hydrochloric acid. The ilmenite, being unaffected by the acid, retained its luster, whereas the magnetite was attacked by the acid, producing a dull-black surface against which the bright ilmenite was easily recognized. He found that the ores consisted in general of aggregates of magnetite and ilmenite, and that the magnetite contained minuter intergrowths of ilmenite, in places regularly intergrown according to the manner already described, and in places irregularly intergrown. The regularly intergrown lamellæ were also found to vary considerably in size and abundance. Five microphotographs of these intergrowths accompanied his article, which so far as known to the author are the only ones that have been published up to the present time.

The lamellar intergrowths of ilmenite were also observed by Warren^d in the Rhode Island ores, and described as follows:

On etching the polished surface with hydrochloric acid, a delicate reticulate structure is developed in the ore. With a direct illumination under the microscope, this structure is seen to consist of an intersecting series of bright-gray, narrow bands or lamellæ inclosing dull-black depressions. This structure extends everywhere through the ore except over occasional small areas which have a smooth surface and are iden-

^a Lacroix, A., op. cit., vol. 4, 1910, p. 317.

^b Mügge, O., Die regelmässigen Verwachsungen von Mineralen verschiedener Art: Neues Jahrb. Min., Geol., Paleon., 1903, B. B. 16, pp. 335-475.

^c Hussak, E., Über die Mikrostruktur einiger brasilianischer Titanmagnetit-eisensteine: Neues Jahrb. Min., Geol., Paleon. vol. 1, 1904, pp. 94-113.

^d Contributions to the geology of Rhode Island. I, Notes on the history and geology of Iron Mine Hill Cumberland by B. L. Johnson. II, The petrography and mineralogy of Iron Mine Hill, Cumberland, by C. H. Warren: Am. Jour. Sci., vol. 25, 1908, pp. 15-16.

tical with the bands in appearance and presumably in composition. The lamellæ are frequently observed to cross at angles of nearly or exactly 60 degrees; again they form a nearly rectangular grating. This structure, taken in connection with the well-known tendency of ilmenite to develop a reticulate structure parallel to the rhombohedral planes, suggests at once that the lamellæ are ilmenite inclosing the more easily dissolved magnetite. The change in direction of the bands in different parts of the ore matrix is the only indication of the existence of individual grains in the ore.

The ratios derived from the rock analysis show conclusively that the two molecules, $RuTiO_3$ and $RuRm_2O_4$, are present, and in about equal proportions. The magnetic susceptibility of particles of the ore, free from olivine and feldspar, was found to be intermediate between that of pure magnetite and ilmenite. It appears, therefore, that the ore matrix consists essentially of an intimate intergrowth of magnetite and ilmenite with an occasional grain of what is probably pure ilmenite. The parallel intergrowth of members of the spinel family with ilmenite has long been familiar to mineralogists, and a similar intergrowth has been suggested by a number of petrographers to explain the composition of the "titaniferous magnetites" of many rocks. Quite recently Hussak has shown by the study of etched surfaces that intergrowths of ilmenite and spinel minerals, particularly magnetite, are very general in the titaniferous ores of Brazil. He also gives a full bibliography of the literature on the subject. It would be extremely interesting to extend the study of titaniferous magnetites still further and ascertain to what extent, if at all, an intergrowth like the one described in the present instance exists in other occurrences. There is still, in spite of the considerable amount of investigation which has been carried on upon "titaniferous magnetites," much uncertainty regarding the exact relations of these two mineral molecules when occurring together.

In order to bring out the relations between the larger ilmenite grains and the magnetite grains of the titaniferous ores of the Adirondacks, Newland^a prepared polished sections which were etched with acid, and he gives three photographs taken with an ordinary camera. It seems, however, that he did not examine the surfaces under magnification and hence overlooked the ilmenite intergrowths within the dull magnetite areas.

METALLOGRAPHIC METHOD OF INVESTIGATION.

The microstructure of the titaniferous magnetites has been studied in this investigation by the application of what is known as the metallographic method. It is a method that has long been employed in metallurgy for investigating the microstructure of the metals and alloys. Polished surfaces of the substance to be examined are prepared and treated with etching fluids, and the structure brought out in this way is observed with a microscope specially constructed for using reflected light, and known as a metallographic microscope.

The instrument used in this work was the Leitz metallographic microscope in the geological laboratory of the Johns Hopkins University. This instrument is so constructed that the objective is inverted and the illumination, which is provided by a small arc light, is reflected upward from below. The object can therefore be

^a Newland, D. H., *Geology of the Adirondacks magnetic iron ores*; N. Y. State Mus. Bull. 119, pt. 3, 1908, p. 151.

placed face downward on the stage, and the polished surface is at once at right angles to the axis of the microscope. This arrangement has the advantage that it does away with the necessity of mounting the specimens, a detail of considerable importance when a large number of specimens are to be studied.

To prepare a polished section, a small piece of ore was chipped or sawed off the hand specimen. The most convenient size was found to be about a half inch square. Elongate pieces were avoided, as it was difficult to keep a plane surface on them in grinding. A little pressure on one side produced a curved surface, and the smallest curvature made the polishing more tedious and necessitated a constant readjustment of the focus of the microscope. The chip was ground down to a plane surface on an ordinary lap wheel, coarse powders being first used, followed by the use of the finest carborundum or emery, until a plane surface had been produced. For the final stages of preparation, a small lap wheel was constructed, run directly by a motor by means of a friction drive. The speed of the wheel could be regulated by changing the gear of the friction drive and by means of a starting box. Duplicate wheels were provided, so that only one kind of powder was used on each wheel. To obtain a smoother surface than was obtained on the large wheel with the finest carborundum, the carborundum was levigated and the finest sediment used on the small wheel. Still better results were obtained when instead of proceeding directly to the polishing stage, the surface was rubbed for a time on a soft whetstone. For this purpose the black stone used in polishing marble was found satisfactory. The final polishing was done with putty powder on a wheel covered with ribless broadcloth.

The polished surface thus prepared was treated with strong hydrochloric acid. The length of treatment necessary to bring out the structure depended greatly on the character of the ore. Coarsely crystallized ore is more quickly acted upon by the acid than fine-grained aggregates. If the etching was not continued long enough, the structure was not well brought out and much detail was lost; on the other hand, if it proceeded too far, the difference in relief became too great and all the details could not be brought into focus at one time. The most satisfactory way was occasionally to remove the specimens from the acid and observe them under the microscope; as soon as the desired contrast was obtained, the etching was stopped.

In preparing the microphotographs accompanying the report a peculiar difficulty was encountered. All the ilmenite intergrowths and the contacts between the larger ilmenite grains and the magnetite showed a blurred effect on one side. Thus, in the case of the linear network, one side of the lines would be perfectly sharp and the other gradually fade away. The author is greatly indebted to Prof. A. H.

Pfund, of the department of physics at the Johns Hopkins University, for the solution of this difficulty. These lines, as well as the other intergrowths, instead of showing on the ground glass as single bright lines showed in the form of spectra; and it was these spectra that were being photographed. Prof. Pfund suggested boring holes in the carbons and filling them with finely pulverized salt and then introducing between the arc and the microscope a filter filled with a solution of potassium bichromate of sufficient strength to cut out all bands of the spectrum beyond the yellow sodium band. In this way what was practically a bright-yellow monochromatic light was produced, as the faint red in this spectrum has no action on the photographic plate. With the aid of this light the blurred effect was eliminated and sharp photographs were produced.

RESULTS OF METALLOGRAPHIC STUDY.

If a polished section of a titaniferous magnetite is treated with hydrochloric acid, the etched surface reveals to the naked eye certain more apparent features of the ore. It is at once seen that the greater part of the section is made up of three principal types of surfaces. Rather light-colored nonmetallic surfaces are at once recognized as the gangue minerals. Dark gangue minerals, which in the unaltered ore can scarcely be distinguished from the ore minerals, magnetite and ilmenite, are bleached and easily recognized. Other parts of the section have remained unaltered and retain their bright metallic surfaces. These consist of grains of ilmenite. Still other areas, made up of grains of magnetite, assume a somewhat dull-black appearance. A closer scrutiny of the magnetite and the ilmenite areas often reveals the presence of minute particles of a nonmetallic mineral that has retained the luster of its polish. These particles are the small spinel crystals so common in the titaniferous ores. Such an etched section is instructive in showing the relations between the grains of magnetite, ilmenite, and gangue minerals. It has the advantage over thin sections of the ores that it brings out more clearly the relations between the ilmenite and the magnetite grains, and the disadvantage that the recognition of the nature of the gangue minerals is more difficult. Photographs of such sections are shown in Plates II, VIII, and IX.

From these plates it is seen that in most cases the relations between the ilmenite and the magnetite grains are those of the constituents of a granular igneous rock. The texture varies from that of a fine-grained rock to that of a coarse-grained rock. As to the relative abundance of the two minerals, in some ores there is little ilmenite and in others the ilmenite greatly preponderates over the magnetite. The relative size of the grains of the two minerals is of the same order of magnitude, though the ilmenite grains average a little smaller

than those of magnetite. The most common shape of the grains is roughly equidimensional, but they also assume an elongate and, especially in the case of the ilmenite, even a tabloid shape. The effect produced then is as if most of the elongated ilmenite grains followed the outlines of the magnetite grains, with a few distinctly cutting across. This is well illustrated in Plate II, *D*. The tabular grains more frequently terminate bluntly, but some gradually fray out at the ends, as in Plate XI, *A*.

A close megascopic examination of the magnetite areas of many ores will show that much of the magnetite is not a homogeneous mass, but is intergrown with minute particles of ilmenite in both regular and irregular orientation (Pl. II, *C*, and Pl. VIII, *B*). A microscopic examination of sections of such ores reveals the intergrowths to much better advantage, and discloses many intergrowths that are so minute as not to be visible to the naked eye. The nature of these intergrowths is fully discussed under the descriptions of the individual deposits. The results of the study of the intergrowths are for convenience summarized at this point.

In many of the ores there is a tendency for small granules of ilmenite to arrange themselves within a magnetite grain very close to its contact with an ilmenite grain. The granules are usually elongate and lie either with their longer axes parallel to the outline of the ilmenite grain, or at right angles to it. In most cases they form a discontinuous fringe around the ilmenite grains from which they are separated by a narrow zone of magnetite free from inclusions. This condition is shown at the right end of Plate II, *E*. Sometimes the granules coalesce, forming a continuous rim about the large ilmenite grain; and if the elongate particles are oriented at right angles to the outline of the grain, the rim may attain a width of 0.2 mm., as in Plate VI, *B*. Besides the particles that tend to segregate along the contact with larger ilmenite grains, others of irregular to more or less circular shape are scattered here and there through the magnetite (Pl. IV, Pl. VI, *A*, Pl. XV, *B*, and Pl. XVI, *A*). The more common size of these is a maximum dimension of 0.1 to 0.3 mm.

The magnetite grains are at times separated by a thin film of ilmenite, so that in section the outlines are marked by a bright rim of ilmenite as is seen in Plate IV, *A*. Somewhat analogous to this is the crowding of regular intergrowths along definite lines in the magnetite areas, which are often the periphery of the grains (Pl. XIII, *B*, and Pl. XV, *A*).

The most common forms of intergrowths are those that show in the sections as lines and as dots.

The lines are sections of minute ilmenite lamellæ oriented parallel to the octahedral faces of the magnetite. Hence in a simple magnetite crystal they can be oriented in three different planes, and in a

twinned crystal in five different planes. In section, this may give rise to three or to five series of parallel lines; the actual number visible depends of course on the orientation of the section. Plate XV, *A*, illustrates the intergrowths in a simple individual; Plate VI, *A*, the intergrowths in a twinned individual. The angles that the lines make with each other depend also on the orientation of the section. If the section lies parallel to the octahedral face, they intersect at 60° ; as the section deviates from this position, the angles approach 0° on the one hand and 90° on the other. But even where the section is so oriented as to expose the three possible directions, intergrowths are not necessarily developed in all three, or at least not equally well developed. Thus, as in Plate III, *B*, the one series of lamellæ is marked by heavy lines, whereas the other two are made up of very small delicate lamellæ. Consequently the pattern produced by the intersecting lamellæ may vary from the equilateral triangular network of a simple magnetite crystal cut parallel to the octahedral face to the more complicated network of five series of intersecting lines in the case of twinned crystals, or to the simplest case of one series of parallel lines, which is most nearly attained in Plate IV, *A* and *B*.

In size the lamellæ range from such as are easily visible with the naked eye (Pl. II, *C*, and Pl. VIII, *B*) to lamellæ so minute as to be scarcely discernible under the highest magnification. The coarsest lamellæ in any of the ores examined occurred in the ores of the Tuscarora mine in Guilford County, N. C. These reach a length of 4 mm. and a thickness of 0.1 mm. They are characterized by local thickenings in the form of protuberances having a thickness as great as 0.2 mm. (Pl. VII, *A*). The distance between the parallel plates averages 0.2 to 0.5 mm., but may be much greater. The plates are distinctly visible to the naked eye and may be peeled off cleavage faces of the magnetite with a knife. Of the other lamellæ examined the only ones approaching the coarseness mentioned were those in the Poplar Lake ore of Minnesota. Aside from these exceptional cases, lamellæ having a length of 1 mm. and a thickness of 0.02 mm. must be regarded as unusually large. Those shown in Plate VI, *A*, and Plate XV, *A*, are among the largest observed.

Generally, instead of one large continuous lamella, there are a number of smaller lamellæ in the same plane, so that in section the effect is that of a broken line instead of a continuous bright line of ilmenite. If unusually thick, they may have a width of 0.02 mm., as in Plate XVI, *A*; but in most cases they are less than 0.005 mm. in thickness, and 0.001 mm. is not at all uncommon. In length every size is represented from lamellæ so minute that their elongation is scarcely discernible to the larger lamellæ mentioned in the preceding paragraph. The delicate short lamellæ showing the broken-line effect are illustrated in Plate IV, *B*, Plate IX, *A*, and in Plate XII, *A*.

As regards the number of lamellæ present, there is also considerable variation. In some ores they are not very numerous and rather widely spaced, as in Plate IV, *A*, Plate XI, *B*, and Plate XVI, *A*. In others they are closely crowded, as in Plate III, *A*, Plate IV, *B*, and Plate VI, *A*. Especially in the case of the more delicate lamellæ the crowding becomes very close, as shown in Plate I, Plate VII, *B*, Plate IX, *A*, and Plate XII, *A*. This crowding becomes in many instances closer and the lamellæ more delicate until the intersecting structure can no longer be discerned, and the magnetite has a peculiar bright luster due to the almost continuous surface of ilmenite. Such grains can easily be distinguished from homogeneous ilmenite grains by the tendency of their luster to show iridescence.

Not only the number but also the distribution of the lamellæ varies greatly. One part of the magnetite surface may be crowded with them so that it shows a closely packed network, and another part, immediately adjacent, may be almost free from intergrowths. Such sudden changes in the distribution of the intergrowths are seen in Plate VII, *B*, and Plate XII, *A*. Then, again, lamellar intergrowths may suddenly terminate and the dots occur in their place as in Plate XI, *B*. Similar to this is the crowding of lamellæ along definite lines in the magnetite, the rest of the area being almost free from lamellæ. These lines are both the outlines between magnetite grains and lines running through the magnetite seemingly with no definite orientation. This effect is illustrated in Plate XIII, *B*, and Plate XV, *A*.

As common as the lamellæ is another variety of intergrowths that show in section as dots with approximately circular outlines. They vary in size from the minutest to the largest, but the impression one receives is that they occur in groups of two sizes—a larger size 0.05 to 0.01 mm. in diameter and a smaller ranging from about 0.002 mm. down to the smallest size observable. Both sizes occur in Plate IV, *B*, and Plate XIII, *A*. Most commonly the dots are irregularly distributed over the magnetite surface, not showing any regular orientation. In some cases, however, they assume a rectilinear orientation parallel to the octahedral cleavages. This is especially prominent with some of the larger dots and is illustrated in Plate XI, *B*, and Plate XIV, *A*. As regards quantity and evenness of distribution the same conditions exist as have been described for the lamellæ. The minute dots may be almost entirely lacking (Pl. XIV, *A*) or they may occur in such numbers as to form almost a continuous surface of ilmenite and produce the peculiar luster on the magnetite that the closely crowded minute lamellæ cause. The uneven distribution of the dots can be seen in Plate XII, *B*, in which there are abundant minute dots at one end and an almost complete absence of them at the other.

One other form of intergrowth has been illustrated in Plate XVI, *B*. This was found in two Canadian ores, the one illustrated from the River Chaloupe and another from a deposit 40 miles north of Montreal. No such intergrowth was observed in any of the ores from the United States. It consists of numerous narrow lenticular bands of what seems to be magnetite, though it is not as readily acted on by the acid as magnetite usually is, intercalated in grains of ilmenite. Hussak^a found what is probably the same kind of intergrowths in the Brazilian ores from Victoria in Espirito Santo and Caldas in Minas Geraes, the former occurring in a quartz mica diorite, the latter in a basic rock. Of the Victoria ore he says: "The large ilmenite grains show a peculiar lamellation after etching and appear to consist of two substances acted on unequally by the acid, although both are very difficultly soluble in 50 per cent hydrochloric acid." The structure would suggest the solidification of a magnetite-ilmenite eutectic and is worthy of further investigation.

It is at once apparent from the microphotographs that all of the intergrowths that have been described are too minute to admit of a mechanical separation. In many cases they are abundant enough to give the magnetite a considerable titanium content, and herein lies the failure to a large extent of magnetic separation to eliminate the titanium from the ores. But it has also been demonstrated that a magnetite showing none of the intergrowths, but etching with a uniform dull-black surface, may carry a large percentage of titanium. A sample obtained by picking particles of etched magnetite free from intergrowths from sections of Sanford Hill ore contained 6.6 per cent Ti. It would appear, therefore, that the magnetite molecule may itself carry titanium and establish the existence of a mineral "titanomagnetite." The titanium content of titaniferous magnetites that is inseparable by means of magnetic concentration, consequently, occurs both in the form of microscopic inclusions of ilmenite and in the magnetite molecule itself. The quantity of titanium occurring in separable and inseparable form is subject to variation between wide limits. Hence it is impossible to predict beforehand what results the magnetic separation of a given titaniferous ore will yield, but each case must be investigated for itself.

CHEMICAL COMPOSITION OF THE TITANIFEROUS IRON ORES.

In the section of this report dealing with the individual deposits of titaniferous iron ores all the available analyses of titaniferous iron ores have been included. At this point some of the characteristic features of the chemical composition of these ores are discussed. The table following gives the average content of the ores, by districts,

^aHussak, E., Über die Mikrostruktur einiger brasilianischer Titanmagnetitesteine: Neues. Jahrb. Min., Geol., Paleon., vol. 1, 1904, pp. 99, 108.

in iron, titanium, phosphorus, and sulphur. The figure in parentheses indicates the number of determinations from which the average is made up. The last column gives the amount of titanium per unit of iron.

Average composition of titaniferous magnetites.

Source of ore.	Fe.	Ti.	P.	S.	Titanium per unit of iron.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Iron Mine Hill, R. I.	33.49 (10)	5.85 (10)	0.016 (5)	0.104 (5)	0.1747
New York gabbro ores.	44.66 (21)	6.28 (21)	.117 (16)	.237 (11)	.1406
New York anorthosite ores.	57.21 (15)	9.61 (15)	.015 (6)	.035 (6)	.1680
New Jersey.	57.83 (40)	1.90 (40)	.289 (40)	.3657 (34)	.0329
North Carolina.	49.98 (58)	6.61 (56)	.023 (36)	.052 (29)	.1323
Minnesota.	49.11 (11)	7.94 (11)	.006 (7)	.126 (7)	.1617
Iron Mountain, Wyo.	49.89 (10)	15.96 (10)	Trace. (1)	.87 (3)	.3199
Caribou Hill, Colo.	45.57 (4)	12.37 (2)	.020 (2)	.....	.2715
Iron Mountain, Colo.	47.86 (11)	7.68 (10)	.026 (8)	Trace. (1)	.1605
Cebolla Creek, Colo. ....	.....	13.61 (2)	.....	.....	.....

One of the most interesting things brought out by this table is the relation existing between iron and titanium. Attempt is made subsequently to show that most if not all of the ores from which the New Jersey averages have been calculated really do not belong to the class of ores under discussion, and hence the New Jersey figures may be ignored. The average titanium content given for the Caribou Hill deposit is beyond doubt wrong. The divergence between Jennings's analysis and Chauvenet's is so great, and the metallographic study of the ore so greatly favors Jennings's determination, that the average of the two certainly does not represent the actual titanium content, but is a figure far above the true value. Hence this average must also be ignored. We then find that the ratio of titanium to iron in the magnetites of all the districts mentioned ranges between the narrow limits of 0.1323 and 0.1747, with the single exception of the magnetite from Iron Mountain, Wyo., which has a ratio twice as great as the average of the others.

The phosphorus content is unusually far below the Bessemer limit. In a few cases, however, the ore contains considerable apatite, which gives it a high phosphorus content. Assumption can not be made, therefore, that a given deposit is low in phosphorus, but it should be tested in this respect. The chances of its exceeding the Bessemer limit are, however, very slight. The sulphur content is also very low, and in no case high enough to produce any deleterious effects.

The geology, origin, and composition of the titaniferous iron ores have been discussed at considerable length by Vogt in a series of articles that appeared in the "Zeitschrift für praktische Geologie" during the years 1893, 1894, 1900, 1901, and 1910. A brief summary of

these results is given in "Die Lagerstätten der nutzbaren Mineralien und Gesteine,"^a by Beyschlag, Krusch, and Vogt.

Vogt finds that the iron-ore segregations occurring in gabbros, labradorfels, and augite and nepheline syenites are characterized all over the world, without exception, by a considerable titanium content. The titanium in the relatively rich segregations rarely falls below 4 to 5 per cent. Another element that is rarely lacking is vanadium in the form of V_2O_5 , and there may also be present Cr_2O_3 , NiO , and CoO . The manganese content is usually low. The apatite or P_2O_5 content is generally low. The quantity of sulphide is usually small, and in a few cases carbon in the form of graphite occurs. A review of the analyses of the titaniferous ores of the United States showed that they conform in every respect to the characteristics outlined by Vogt.

As regards their manner of occurrence, Vogt states that they occur in the central parts of the eruptive masses into which they gradate as irregular schlieren, or as distinct dikes with sharp contacts against adjacent eruptive rock. All these types of occurrences are represented among the deposits of the United States. The manner in which the differentiation progresses is discussed by Vogt and is illustrated graphically by diagrams, and the theory of the processes of differentiation is considered. A consideration of these points is, however, beyond the scope of this report.

Of more immediate interest is Vogt's discussion of the relations of the iron, titanium, phosphorus, and sulphur of the ores to the original content of these elements in the magma. Omitting certain analyses that he regarded as unreliable, the analytical results collected by him covering occurrences all over the world showed that the ratio between titanium and iron ranges between 0.063 and 1. Only in rare cases, however, does the ratio fall without the limits 0.1 and 0.667; and in the vast majority of cases of segregations within gabbros and anorthosites relatively rich in iron-magnesian silicates the ratio lies between 0.111 and 0.250. The table on page 35 shows that all of the American occurrences, ruling out those of New Jersey and Caribou Hill for reasons already stated, fall within this narrow limit with the exception of the Iron Mountain, Wyo., deposit. This deposit occurs in anorthosite relatively poor in ferromagnesian minerals, and such deposits Vogt states are characterized by a higher titanium content. A thoroughly trustworthy ratio of titanium to iron in the original gabbroitic magma can not be given, but he regards it as falling below 0.1 to 0.125. Hence in the processes of differentiation not only has there been an absolute enrichment of iron and titanium, but titanium has to a varying extent been enriched relatively to the iron.

According to Clarke,^a the eruptive rocks carry an average of 0.11 per cent of phosphorus and 0.11 per cent of sulphur; but the gabbroitic rocks carry more than the average quantity of these two elements, and Vogt assumes as the minimum an average of 0.2 per cent of phosphorus and 0.15 per cent of sulphur for these rocks. The average phosphorus content of the titaniferous iron ores is far below this figure, and in only a few cases does it reach that quantity in individual deposits. The high-grade ores usually carry only the minutest quantity of phosphorus. The sulphur content is also usually very minute. In a few cases there is a considerable sulphur content in the ores owing to the presence of sulphides, but in most cases the average is below the average for the magma. Consequently, the assumption is warranted that while the iron and titanium were being enriched to form the ore bodies the phosphorus and sulphur remained in the magma. In other cases there have been segregations of apatite and of sulphidic ores. Vogt concludes, therefore, that the conditions favorable to the segregation of iron and titanium differ from those favorable to the segregation of phosphorus, and these again from those favorable to the segregation of sulphides; and that in most cases these conditions do not exist at the same time or place.

He also takes up the behavior of some of the less essential constituents of the ores in this respect. A slight enrichment of manganese has taken place, but not to the extent to which iron has been enriched. Kemp found that chromium and vanadium vary in the same manner if not absolutely in the same degree. This relation is corroborated and the average enrichment of these two elements in the ores given as tenfold. The nickel and cobalt content is usually small and in most cases less than one would expect.

In conclusion, it may be stated that the characteristics of the chemical composition of the titaniferous iron ores of the United States are the same as those that mark these ores the world over. As regards iron content most of them must be classed as medium to low grade ores. Fortunately, however, the deposits with the greatest economic possibilities are the richest and their ores are high grade. Phosphorus and sulphur are present in objectionable quantities in only rare instances; and phosphorus especially is unusually low in the most promising deposits. The slag forming compounds, lime, magnesia, alumina, and silica, are present almost entirely in the gangue minerals, and play no important rôle in the composition of the ores. The high-grade ores in which the iron content is high enough for direct furnace use contain little gangue. The lower-grade ores would have to be subjected to magnetic concentration to bring their iron content within the required limits, and this would reduce

^a Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911.

the percentage of those constituents in the concentrates to a minimum.

ECONOMIC IMPORTANCE OF THE DEPOSITS.

The field investigation of the titaniferous iron ores has given the author the impression that the possibilities of these ores with reference to the iron-ore resources of the country have been grossly exaggerated in many quarters. In the detailed description of the more important deposits of these ores that follows, their commercial aspect is discussed so far as available data make this possible, and the statements made here are in the nature of conclusions based on those discussions.

Least promising are the possibilities of the ores in the ferromagnesian rich rocks. As a general rule, the deposits are of small and irregular extent, and the ores fine grained and lean. Leaving out of consideration for the moment their titanium content, they are ores that would require magnetic concentration before they could be used in the blast furnace. Further, most of the deposits are inaccessible to adequate transportation facilities. Their situation both topographically and with regard to the industrial development of the country at large is such that there are no prospects of transportation facilities being provided for a long time to come. Hence, to put these deposits on a producing basis, the heavy initial expense would have to be incurred of erecting magnetic concentrators and providing adequate transportation facilities. The small extent of most of the deposits and their irregular distribution make those costs prohibitive. Then, their titaniferous character must be taken into consideration. The relations of ilmenite and magnetite in the ores are such that the least favorable results would be obtained in the elimination of titanium by magnetic concentration. In fact, the titanium would be increased together with the iron; so that the higher the iron content of the concentrates, the higher would be their titanium content.

In the case of the ores in the anorthosites and the feldspar-rich gabbros, the conditions are much more favorable. As a general rule the ores are much coarser grained and richer. This tendency to coarser-grained, rich ores is noticed where the gabbros assume an anorthositic facies. Thus in some of the feldspathic phases of the Duluth gabbro, in Minnesota, the ores are coarser grained than the normal gabbro ores, and small segregations of comparatively pure ore occur. Also at Iron Mountain, Colo., the immediate country rock shows an anorthosite phase, and the ores are richer and coarser grained than ordinary gabbro ores and greatly resemble the typical ores in anorthosite.

Two deposits in anorthosite stand out above all other titaniferous iron-ore deposits in the United States; these are at Sanford Hill, N. Y., and Iron Mountain, Wyo. At each of these localities, in addition to the one enormous deposit, there are smaller but important deposits with the same kind of ore. At neither place has a careful estimate of available tonnage been made, but it is apparent from the known extent of the deposits that the quantity of ore that can be mined by simple quarrying methods alone runs into millions of tons. The ores are nearly pure aggregates of magnetite and ilmenite, the gangue minerals being so subordinate in amount as to be negligible. The average composition of the Adirondack ore corresponds to 62.8 per cent magnetite and 30 per cent ilmenite, whereas that of the Wyoming ore is equivalent to 49.8 per cent magnetite and 40.15 per cent ilmenite. The results of magnetic concentration tests show that the Adirondack ore would yield a concentrate containing less than 7 per cent Ti and the Wyoming ore a little less than 10 per cent. The titanium content of the Adirondack concentrate is low enough to make feasible its mixture with several parts of nontitaniferous ore to make a product low enough in titanium to be used in ordinary blast-furnace practice. The low phosphorus and sulphur content of the concentrate would make it a desirable material for mixing with ores of non-Bessemer grade and high in sulphur. The concentrates of the Wyoming ore are rather high in titanium for this purpose, and it is probable that these deposits will have to await some such process as electrical smelting that will make possible the direct smelting of titaniferous ores. To provide adequate transportation facilities for the Sanford deposit will require the construction of more than 30 miles of railroad over a mountainous country; for the Iron Mountain deposit, only 10 miles will be necessary, and the construction will be much easier. In both cases the deposits are large enough to warrant this expense.

To sum up, it may be confidently asserted that the Lake Sanford and Iron Mountain, Wyo., deposits are important ore bodies that before many years will be furnishing a considerable tonnage of iron ore. The rest of the titaniferous iron-ore deposits of the United States can not for many years to come be of any value as sources of iron ore.

CHARACTER, SITUATION, AND POSSIBILITIES OF THE DEPOSITS.

In the subsequent pages the more important deposits of titaniferous iron ores in the United States are described individually. The order of treatment is geographic, beginning in the northeast with Rhode Island and continuing southward and westward. The method

pursued has been to give first a summary of the geologic features of a given deposit in order to prepare the way for an adequate discussion of the metallographic features of its ores and of its economic possibilities.

RHODE ISLAND

IRON MINE HILL DEPOSIT.

The titaniferous magnetic iron ore of Iron Mine Hill, R. I., has been known for over two centuries, and has been of such interest to geologists that repeated mention of the deposit is made in geological literature. The most recent and thorough study of this deposit is that by Johnson and Warren,^a who made a careful study of the deposit itself, and included in the presentation of their results a historical account of the deposit and a summary bibliography of the pertinent literature. In view of this thorough study and careful description of the deposit, the author of this report has not deemed it necessary to revisit the locality. The following description of the deposit being based chiefly on the paper by Johnson and Warren.

LOCATION.

Iron Mine Hill lies in the northeast corner of Rhode Island, near the Massachusetts line, in the town of Cumberland, about 3 miles east of Woonsocket. The region is heavily drift covered and of moderate relief, the hills not rising much more than 100 feet above the surrounding country. One of these hills consists of a heavy rock which early attracted attention as a possible source of iron ore, and it has since received the name Iron Mine Hill. The dimensions of the hill as given by Jackson^b are 462 feet long, 132 feet broad, and 104 feet high. The area occupied by the ore body is even larger. The exact boundaries are covered, but it appears from surface indications and magnetic observations that the ore body has a length of 1,200 feet and a width of 500 to 600 feet. The direction of the longer dimension is nearly north and south.

HISTORY.

Repeated attempts have been made to utilize this ore. As early as 1703 it was mixed with hematite from Cranston, R. I., and used in a foundry probably located in the town of Cumberland. Part of the cannon used against Louisburg in 1745 were made at this forge, and the ores were utilized for this purpose during the Revolutionary War. Attempts were made to use the ores during the early and middle parts of the last century by mixing them with high-grade

^a Contributions to the geology of Rhode Island. I, Notes on the history and geology of Iron Mine Hill, Cumberland, by B. L. Johnson. II, The petrography and mineralogy of Iron Mine Hill, Cumberland, by C. H. Warren: *Am. Jour. Sci.*, 4th ser., vol. 25, January, 1908, pp. 1-38.

^b Jackson, C. T., Report on the geological and agricultural survey of the State of Rhode Island, 1840, p. 52.

ores at furnaces in New York, Pennsylvania, and New England. In all several thousand tons of ore have been used. The great drawback has always been their low iron content and the high percentage of titanium that they carry. The enormous quantity of the ore and the low phosphorus and sulphur content have been advantages that have partly offset the disadvantages. However, no attempt to work the ores for their iron has been made for many years, and an attempt to use the rock for road metal (macadam) at the close of the last century also met with failure, probably because its extreme toughness made its quarrying too expensive.

ORIGIN.

Jackson^a was the first to recognize the eruptive character of the ore. The first microscopic study of the ore was made in 1881 by Wadsworth,^b who called attention to its similarity to the celebrated iron ore of Taberg, Sweden. Though the origin of the rock could not be told from its field relation, he considered that its mineral association and microscopic characters indicated that it was an eruptive rock. He therefore concluded that the deposit was of eruptive origin. In 1884, Wadsworth^c proposed the name cumberlandite for this and similar rocks.

Opposed to the eruptive theory at this time were men like Hitchcock^d and Dana,^e who considered the magnetite to be of metamorphic origin.

At present the igneous origin of the cumberlandite is not doubted, the general opinion being it is probably a segregation from a gabbroitic magma.

GENERAL FIELD RELATIONS.

Unaltered cumberlandite is exposed at only one point on the western slope of the hill. This area of fresh rock, about 300 to 400 square feet, passes over, with a comparatively narrow transition zone, into the altered types that form the greater part of the hill. One of the first changes in the rock consists in the alteration of the feldspar phenocrysts to dark-green chloritic aggregates, in association with which a little actinolite may occur. Such rock makes up the greater part of the exposures. As alteration progresses the olivine also passes into chlorite and actinolite, and in the final stage olivine and actinolite are changed to serpentine. The analysis cited below, from Wadsworth, was probably that of a sample of ore in which the feldspar had undergone changes.

^a Op. cit., p. 53.

^b Wadsworth, M. E., A microscopic study of the iron ore, or peridotite, of Iron Mine Hill, Cumberland, R. I.: Mus. Comp. Zool. Harvard College Bull. 7, 1881, pp. 183-187.

^c Wadsworth, M. E., Lithological studies: Mem. Mus. Comp. Zool. Harvard College, vol. 11, 1884 p. 80.

^d Hitchcock, Edward, Final report on the geology of Massachusetts, 1841, p. 554.

^e Dana, J. D., Iron ore of Iron Mine Hill, Cumberland, R. I.: Am. Jour. Sci., 3d ser., vol. 22, 1881, p. 152.

The rock is cut by a major system of joints that is parallel to the long direction of the hill and has a nearly vertical dip. A minor series of joints, approximately at right angles to these, cuts the hill into small, rudely prismatic blocks. Many of these blocks have been plucked out by the ice, leaving an irregular broken surface. Shearing movements which have produced a schistose structure in the secondary actinolite and chlorite formed along the joint planes.

The cumberlandite is nowhere exposed in contact with any other rock, and is separated from the nearest outcrops by barren areas for a distance of at least 700 feet. The surrounding rocks consist of green chlorite-epidote schist and quartzose biotite schist cut by numerous quartz veins and granite dikes, granite, diabase, and a coarse-grained metamorphosed gabbro. The gabbro extends in a series of heavily glaciated ridges around the west side of the hill for a distance of three-quarters of a mile, obtaining a width of one-quarter of a mile. It is everywhere separated from the cumberlandite by swamps and drift, so that no contact can be observed.

The occurrence of inclusions of gabbro in the cumberlandite at several places indicates a not distant contact. Moreover, a line connecting the known northeastern and southeastern limits of the gabbro would pass close to the supposed western limit of the cumberlandite. The evidence, therefore, indicates the intrusion of the cumberlandite into the gabbro. The basic character of both, their titanium content, and their occurrence as adjoining masses surrounded by genetically unrelated rocks suggested to Johnson that they are offshoots from a common magma. Such a differentiation within the magma and subsequent intrusion of the one differentiate into the other instead of differentiation in situ has, according to the observations of the author, very frequently occurred in the case of the titaniferous magnetites. Though this deposit has many features in common with the well-known Taberg deposit in Sweden, resemblances that are just as strikingly brought out in the metallographic study of the two ores, this is one essential difference in the two deposits. The Taberg ore is an example of differentiation in situ. The ore, a magnetite olivene, has segregated in the center of a mass of *olivine* hyperite. Here there is a transition from country rock to ore; at Iron Mine Hill, the ore was intruded into the gabbro, and if exposed the contact would be sharp and not gradational.

The gabbro is not cut by the surrounding granite, and no inclusions of the granite or sedimentaries in the gabbro are known. Positive evidence of the relative ages of the gabbro and the surrounding rocks is lacking. Johnson^a suggests that the gabbro is younger than the schists but older than the granite, since such a sequence has been determined in the case of a mass of gabbro surrounded by schist

^a Johnson, B. L., and Warren, C. H., Contributions to the geology of Rhode Island: *Am. Jour. Sci.*, 4th ser., vol. 25, January, 1908, pp. 10-11.

and granite at Norwich, Conn., about 80 miles southwest of Cumberland.

The gabbro was originally a rather coarse-grained rock, consisting of labradorite, averaging about Ab_1An_1 , a purplish augite of distinctly diabasic habit, an unusual proportion of ilmenite in the form of large grains closely associated with the augite, and accessory apatite. Shearing and metamorphism have affected the gabbro mass unevenly. The central and southern parts are least affected; the northern parts have been more severely altered, and in part changed into fissile green schists.

CUMBERLANDITE.

The cumberlandite has a characteristic appearance and can be readily distinguished macroscopically from all other known titaniferous magnetites in the United States. In a grayish-black, fine-grained groundmass of irregular fracture are embedded relatively large tabular crystals of plagioclase. Two constituents of the groundmass can be recognized with the eye alone. One is a yellowish glassy olivine, the other a grayish-black mass of magnetite and ilmenite.

Plagioclase makes up about 13 per cent of the rock. The crystals average 1 cm. square by 2 mm. thick and range in size from minute grains to a maximum of 2 cm. square by 2 to 3 mm. thick. The common segregation of two or more feldspar crystals gives the rock a cumulophyric texture. Locally a tendency to parallel or fluidal arrangement is noticeable, but there is no persistent direction of orientation maintained. Though the feldspar is more abundant in one place than in another, it has a fairly uniform distribution throughout the rock.

At the contacts between the feldspar and the groundmass reaction rims are always developed; but they are exceedingly narrow, ranging from 0.003 to 0.01 mm. At the feldspar-olivine contacts, the reaction rim consists of pale-green to colorless needles of actinolite that are perpendicular to the contact. At many ilmenite-magnetite-feldspar contacts shreds of biotite appear; and in some places they occur as a narrow border next to the magnetite, with a border of actinolite on the feldspar side.

The texture of the groundmass is well shown on a polished surface of the ore, especially after etching with strong hydrochloric acid, which causes the dark glassy olivine to lose its high luster and to stand out as a light-yellow lusterless substance in a network of magnetite and ilmenite. The olivine occupies somewhat more than half of the surface.

In thin sections the olivine is seen to consist of a mosaic of anhedral grains ranging in size from minute particles to individuals 5 mm. long by 2.5 mm. wide. In general the olivine lacks crystallographic outlines, yet throughout the rock the magnetite-ilmenite

acts as the matrix. The following analysis, made by Warren, shows it to be a hyalosiderite:

Results of an analysis of olivine from cumberlandite.

	Per cent.
SiO ₂	37.16
TiO ₂	.07
Fe ₂ O ₃	.12
FeO.....	31.38
MnO.....	.40
CaO.....	Trace.
MgO.....	31.16
Feldspar (insoluble).....	.34
	100.63
Fe.....	24.5

Spinel occurs at random in the ore in the form of minute subangular grains, reaching a maximum size of 0.45 mm. by 0.12 mm. More commonly they are equidimensional grains averaging 0.10 to 0.20 mm. in diameter. The spinel is seen in thin sections as a dark-green, feebly transparent isotropic mineral, which was called glass by Wadsworth, but thought to be hercynite by G. H. Williams. Warren calls it pleonaste.

CHEMICAL COMPOSITION OF ORE.

The results of a number of analyses of cumberlandite are available, but the only complete one is that made by Warren. The available results are presented below:

Results of analyses of Iron Mine Hill ore.

Constituent.	1 a	2 b	3 c	4 d	5 e	6 f	7 g	8 h	9	10 j
SiO ₂	22.35	23.00	22.87	20.85	20.85	20.77	}26.33	{.....	.....	20.41
Al ₂ O ₃	5.26	13.10	10.64	5.55	5.26	4.01				
Fe ₂ O ₃	14.05	27.60	}44.88	45.62	{16.32	17.22	}58.50	.....	.....	.....
FeO.....	28.84	12.40								
TiO ₂ k.....	10.11	15.30	9.99	9.93	9.63	10.08	3.66	9.35	9.86	11.75
MnO.....	.43	2.00	2.05	.....	.....	2.10	.....	.....	.....	.05
CaO.....	1.17	.....	.65	.73	.98	.53	.65	.....	.....	.....
MgO.....	16.10	4.00	5.67	16.45	17.60	17.96	6.80	.....	.....	.....
Zn.....	.71	.....	.20	.....	.....	.....	.....	.....	.....	.....
H ₂ O.....	.42	2.60	3.05	.....	.66	2.70	1.96	.....	.....	.....
P ₂ O ₅	.02	.....	.....	Trace.	.....	.....	.....	.026	.026	.103
S.....	.38	.....	.....	Trace.	.....	.....	.....	.057	.057	.023
V ₂ O ₅	.18	.....	.....	Trace.	.....	.....	.....	.....	.....	None.
Cr ₂ O ₃	Trace.	.....	.....	.....	.....	.....	.....	.....	.....	.....
Na ₂ O.....	.44	.....	.....	.....	.....	.....	.....	.....	.....	.....
K ₂ O.....	.10	.....	.....	.....	.....	.....	.....	.....	.....	.....
CO ₂	.02	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cu.....	.08	.....	.....	.....	.....	.....	.....	.....	.....	.....
Co-Ni.....	.08	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pb.....	Trace.	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total.....	100.74	100.00	100.00	99.13	99.83	99.78	100.00	.....	.....	.....
Fe l.....	32.5	28.96	32.49	33.03	33.67	32.73	42.35	32.80	32.84	33.87

a Warren, C. H., Contributions to the geology of Rhode Island. The petrography and mineralogy of Iron Mine Hill, Cumberland: Am. Jour. Sci., 4th ser., vol. 25, January, 1908, p. 24.

b Jackson, C. T., Geol. Survey of R. I., op. cit., p. 53.

c Thurston, R. H., quoted by Wadsworth: Mus. Comp. Zool. Harvard College Bull. 7, 1881, p. 185.

d Brown, T. M., quoted by Wadsworth: pp. 16-17.

e Packard, R. L., quoted by Wadsworth, M. E.: Mem. Mus. Comp. Zool. Harvard College, vol. 11, pt. 1, 1884. Report of the State Board (of Michigan) Geol. Survey for the years 1891-92. Lansing, 1893, p. 95 (ore with feldspar).

f Same as foregoing (ore without feldspar).

g Chilton, —, quoted by Holley, A. L.: Trans. Am. Inst. Min. Eng., vol. 6, 1878, p. 226.

h Tenth Census U. S., vol. 15, 1886, p. 567.

i Same as foregoing, but dried.

j Data furnished by W. L. Cumings, of the Bethlehem Steel Co.

k Average, 9.75.

l Average, 33.49.

Calculating its position in the quantitative classification, Warren found that the ore fell in an order and rank for which there was no name, and at the suggestion of Prof. L. V. Pirsson he proposed the names rhodare and rhodose from the State in which the rock occurs. The stem cumberland was rejected in order to prevent confusion with the better known town of Cumberland in England. The mode as calculated by Warren is given below.

Mode of cumberlandite.

Mineral.	Percentage by weight.	Percent- age by volume.
Orthoclase.....	0.56	0.8
Labradorite (Ab_3An_1).....	9.23	13.7
Olivine.....	46.08	49.4
Magnetite.....	20.65	15.9
Ilmenite.....	18.63	15.2
Spinel.....	3.55	3.9
Sulphides.....	1.15	1.1

Because the name cumberlandite is widely known its use in this discussion has been deemed advisable.

METALLOGRAPHIC DESCRIPTION OF THE ORE.

As already stated, the ore minerals form the matrix for the olivine and the other minerals of the groundmass. They occur in irregular areas of about the same size as the olivine grains or a little smaller, and except in the altered phases are more or less connected with each other. They form a little less than 50 per cent of the groundmass.

When a polished surface of the ore is etched with hydrochloric acid a part of the ore remains bright, whereas the greater part shows a dull black background on which a delicate reticulate structure has been developed. The bright grains, which are ilmenite, are usually quite small, rarely having a maximum dimension of 2 mm., and form only a small percentage of the ore. The reticulated structure of the ilmenite growth in the magnetite is especially characteristic in this ore. It is marked by the minuteness of the lines and the closeness with which they are crowded. They range in fineness from such as are shown in Plate I, *A*, down to such minute intergrowths as not to be resolvable by the magnification used in the figure. Such areas are distinguishable under the metallographic microscope from areas of true ilmenite by their peculiar iridescent luster. The coarsest of the lines attain a length of only 0.15 mm. The same delicate minute network is also characteristic of the Taberg ore with which the Iron Mine Hill ore has so often been compared geologically. The similarity of the structure is brought out in Plate I, *A* and *B*.

The metallographic features of this ore distinguish it from all the other American ores that were studied, as is at once apparent from a comparison of the microphotographs shown in this report.

POSSIBILITIES OF UTILIZATION.

The size of the deposit and its low phosphorus and sulphur content would indicate the desirability of working it. However, more than offsetting these advantages are its low iron content and its titaniferous character. The low percentage of iron could be overcome by magnetic separation were not the character of the ore such as to make magnetic concentration impracticable. The magnetite and the ilmenite are so intimately intergrown that with the exception of the larger grains of ilmenite the ilmenite would be concentrated equally with the magnetite.

The result of a perfect separation of the ilmenite and the magnetite from the gangue minerals can be calculated from the mode of the rock given above. About one-third of the iron of cumberlandite is contained in the olivine, and this would go into the tailings, leaving only two-thirds or about 22 per cent Fe for the concentrates. Again, assuming that one-third of the titanium could be removed by the separation of the larger grains of ilmenite, a percentage greater than is actually the case, the iron would be still further decreased by more than 2 per cent and the titanium by nearly 2 per cent. Such a perfect concentrate would contain, therefore, 20 per cent of cumberlandite in the form of iron and 4 per cent in the form of titanium, in a bulk one-third by weight of the original rock. In other words, it would take 3 tons of ore to produce 1 ton of concentrates analyzing 60 per cent Fe and 12 per cent Ti.

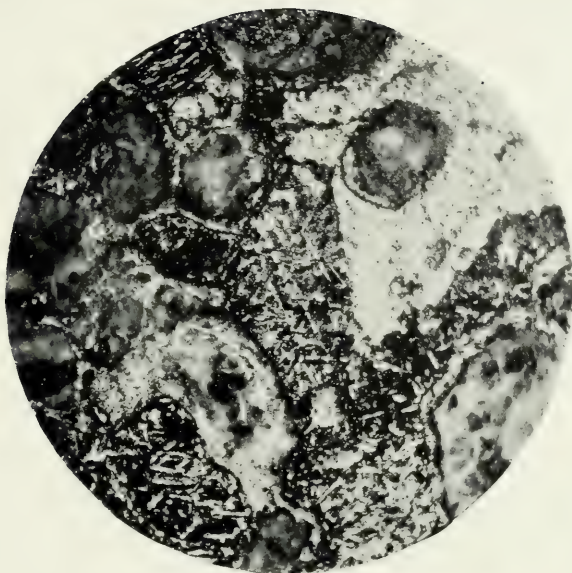
A concentration made on a commercial basis would show results still less favorable. The percentage of iron would fall below 60 per cent without a corresponding decrease in titanium, as, with a less complete separation, a smaller percentage of ilmenite than that assumed above would be removed. Consequently the cost of obtaining the degree of concentration necessary to produce a product high in iron would be excessive, even if the resulting product would not be unsalable on account of its high titanium content.

NEW YORK.

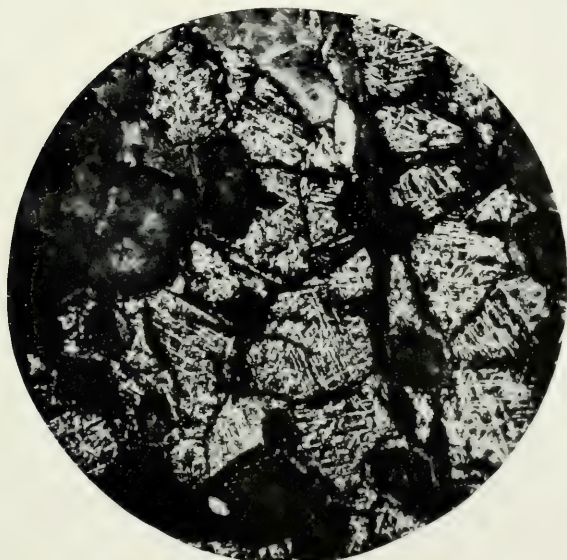
Titaniferous iron ores occur in New York State in the Adirondack Mountains and on the east bank of the Hudson River below Peekskill.

DEPOSITS IN THE PEEKSKILL REGION.

At this locality there is an area of about 25 square miles that consists of rocks of the gabbro family known as the Cortlandt series. Associated with these rocks are highly aluminous titaniferous ores



A. IRON MINE HILL, R. I., ORE. (X 60.)



B. TABERG, SWEDEN, ORE. (X 60.)

which have attracted considerable attention both as a source of iron and as a source of emery. These ores differ from normal titaniferous magnetites in their low titanium content and in the high percentage of alumina that they carry. The percentage of TiO_2 ranges from 0.15 to 4.15 per cent, and that of alumina from 20 to nearly 50 per cent. Mineralogically they consist of spinel, magnetite, and corundum. The percentage of iron ranges from about 30 to 40 per cent, but averages about 33 per cent. The deposits do not seem to be of any importance from the standpoint of iron ores, and their titanium content is so low as not to seriously interfere with their use in ordinary blast-furnace practice, especially if mixed with nontitaniferous ores. Hence no special study of them was made in connection with this report. They have been described by Dana ^a and by Williams.^b

DEPOSITS IN THE ADIRONDACK REGION.

The titaniferous magnetites of the Adirondack region belong to the normal type. The ores have been studied in considerable detail by Kemp, and in his papers are more fully described than any other deposits of titaniferous ores in the United States. The most complete account is that on "The Titaniferous Iron Ores of the Adirondacks."^c More recently Newland ^d published an account of these ores, which, however, he says is based chiefly on the descriptions and conclusions of Kemp. The deposits in the gabbros in the townships of Elizabethtown and Westport were again described in 1910 by Kemp, some additions being made to the earlier descriptions.^e These articles refer to previous contributions and include the information available at the time they were written. The following descriptions of the occurrences are based chiefly on Kemp's accounts, and are supplemented by additional information taken from Newland's bulletin and observations made by the author at those deposits visited by him.

DISTRIBUTION OF THE ORE DEPOSITS.

The titaniferous ores of the Adirondacks are associated in all but one doubtful case with rocks of the gabbro family. Consequently their distribution is determined by that of the gabbro rocks. The principal area of these rocks is in Essex and southern Franklin Counties, where they occupy about 1,200 square miles. Smaller outlying intrusions are found in Clinton and Warren Counties and in the

^a Dana, G. D., Geological relations of the limestone belts of Westchester County, N. Y.: *Am. Jour. Sci.*, 3d ser., vol. 20, 1880, pp. 199-200.

^b Williams, G. H., The norites of the "Cortlandt series" on the Hudson River near Peekskill, N. Y.: *Am. Jour. Sci.*, 3d ser., vol. 33, 1887, pp. 194-199.

^c Kemp, J. F., 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 377-422.

^d Newland, D. H., Geology of the Adirondack magnetic iron ores: *N. Y. State Mus. Bull.* 119, pt. 3, 1908, pp. 146-170.

^e Kemp, J. F., and Ruedemann, R., Geology of the Elizabethtown and Port Henry quadrangles: *N. Y. State Mus. Bull.* 138, 1910, pp. 137-149.

western Adirondacks. Most of the deposits occur in the townships of Westport, Elizabethtown, and Newcomb, in Essex County.

FIELD RELATIONS OF THE ORES.

The principal geological features of the deposits are concisely stated by Kemp ^a and his account is quoted nearly in full in the paragraphs following:

The titaniferous ores of the Adirondacks are associated in all cases ^b with rocks of the gabbro family and with two well-marked varieties belonging to it. The two are contrasted in appearance and are easily recognized. The largest ore bodies are contained in rocks that are chiefly labradorite, in the coarsely crystalline granitoid aggregates that have been called anorthosite by the Canadian geologists, within whose territories they are abundant. A little augite or hypersthene is always present in a very subordinate capacity, and rims of garnet are common around the bisilicates. The ores in anorthosites are limited to Newcomb, Wilmington, and North Hudson townships, and lie among the highest peaks of the mountains. In their geological associations and general character they are practically like the huge masses of ore that occur along the lower St. Lawrence in Quebec and near Ekersund in southwestern Norway.

The smaller ore bodies, although still of very considerable size, are found in a dark basic gabbro or norite, in which the ferromagnesian silicates predominate over the feldspar. Labradorite is the feldspar and green augite the chief bisilicate. Hypersthene is sometimes abundant and olivine is frequently present. Small garnets in granular rims about the bisilicates are quite invariably present, and shreds of biotite are by no means uncommon. Brown hornblende is an important constituent in and near the ore, and is also common throughout the mass of the rock. Small, irregular anhedral of titaniferous magnetite are always disseminated in the gabbro, and apatite is, of course, not lacking. In texture the rock approximates the diabasic granular type, because of the marked tendency of the feldspar to form lath-shaped individuals.

The ores in the gabbro are contrasted in physical appearance with those in the anorthosite. The former are closely crystalline and dark gray, with a dense, compact aspect, like a finely crystalline igneous rock. The titaniferous magnetite is in relatively small individuals and is mingled with ferromagnesian silicates. The ore from the anorthosites is coarsely crystalline, like ordinary magnetites. It sometimes has a bluish shade, which is regarded by many as characteristic. It lacks the abundant ferromagnesian silicates, and contains large feldspars instead. The greater coarseness of crystallization is in great part due to the larger masses in which it occurs. The contrasts in the grain of the ores, however, are fully reproduced in the textures of the wall rocks, and the ores vary with the varying conditions under which each has crystallized.

The anorthosites and gabbros belong to a great series of intrusives which have come up through older gneisses and crystalline limestones. Considered in their entirety, the intrusives embrace other varieties of gabbroic rocks than the two just cited, varieties that lie between them as extremes, but as the intermediate types are not immediately concerned with the ores they are not described in further detail. The

^a Kemp, J. F., The titaniferous iron ores of the Adirondacks: 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 397-399.

^b A single exception is the Port Leyden mine in Lewis County, outside of the main gabbro area. The immediate wall rock of the deposit is not exposed, but it seems to be associated with quartz gneisses containing potash feldspar. The anomalous relations of this deposit are probably only apparent and it seems reasonable that, as Newland suggests, "it may be related to some underlying magma from which the ore body represents an offshot, perhaps intrusive in the granitic gneiss." One should hesitate to consider a deposit whose relations to its wall rock are as obscure as in this case an exception to a rule of such general application.

intrusives correspond to the Norian of the Upper Laurentian of the Canadian geologists, and the gneisses and crystalline limestones are the representatives of the Canadian Grenville series. In the nomenclature adopted by the United States Geological Survey, both the older rocks and the intrusives must be included in the Algonkian on account of the presence of the limestones. After the intrusions of the gabbros and anorthosites the Adirondack region was subjected to great dynamic metamorphism, so that the massive rocks were crushed and often drawn out into gneisses, and so involved with the older formations as to greatly obscure the stratigraphical relations. It is rather rare to find one of the Norian massive rocks that does not display some evidence of this metamorphism, but in a few cases limited areas of the dark gabbros have escaped it to a greater or less degree, and in the western part of Essex County the anorthosites are not greatly affected.

DESCRIPTION OF OCCURRENCES IN ELIZABETHTOWN, WESTPORT, AND MORIAH TOWNSHIPS.

Only those occurrences that were visited by the author are described. They include nearly all the more important deposits and are sufficiently characteristic to establish clearly the nature of the ores.

SPLIT ROCK MINE.

The Split Rock mine is located on the west shore of Lake Champlain in a small cove, a half mile above Snake Den Harbor and 5 miles northeast of Westport. It is on a steep hillside overlooking the lake. The hill is a spur of Split Rock Mountain which is a long ridge running parallel to the lake shore. Split Rock Mountain consists chiefly of anorthosite with some gabbro. The wall rock of the ore is a highly garnetiferous gabbro. The garnet occurs throughout the rock in small clusters of nearly black crystals, giving the rock a peculiar mottled appearance. The plagioclase of the gabbro consists of nuclei swarming with minute inclusions of pyroxene and probably spinel, surrounded by areas of clear feldspar. The garnet tends to occur in the areas of clear feldspar and closely associated with the feric minerals. Cutting the rock and the ore are small dikes of a white rock varying from a few inches to a foot in thickness. In thin section this rock is seen to consist almost entirely of saussurite with a few scattered bunches of augite, garnet, and hornblende.

Three ore bodies outcrop within a distance of 200 feet. The larger of these, which is the more southerly, has a width of about 10 feet. Two openings have been made on this ore body about 20 feet apart. An opening has also been made in the most northerly of the three deposits.

These ore bodies are magnetite-rich lenses into which they grade by gradual transition. Most of the ore is a dark-colored fine-grained rock of seeming good quality, but polished sections show that it is a very lean ore. Plate II, A, shows a specimen of the ore that has been polished and then leached with concentrated hydrochloric acid until the gangue minerals are all light colored. The relations and

relative quantities of ore minerals and gangue are well brought out. A small amount of coarser-grained ore occurs and this carries little gangue. A peculiar feature of this ore and the ore from Little Pond, which has been described by Kemp, is the occurrence through it, in veinlets and in crusts coating the bounding surfaces of cracks, of a green isotropic material which is presumably a basic glass; the relations of the glass to the ore are such as to indicate a primary origin that is a most anomalous phenomenon in a plutonic rock. The following results of analyses of wall rock and ore are taken from Kemp:

Results of analyses of Split Rock gabbro and ore.

Constituent.	1a	2b	3c
SiO ₂	47.88	17.10	16.46
TiO ₂	1.20	15.66	14.70
Cr ₂ O ₃	Trace (?)	.51	.....
Al ₂ O ₃	18.90	10.23	.34
Fe ₂ O ₃	1.39	15.85	38.43
FeO.....	10.45	27.94	23.40
NiO.CoO.....	.02	(d)	(d)
MnO.....	.16	Little.	.23
CaO.....	8.36	2.86	3.54
SrO.....	Trace.	.....	.....
BaO.....	Trace.	.....	.....
MgO.....	7.10	6.04	2.13
K ₂ O.....	.81	(d)	.....
Na ₂ O.....	2.75	(d)	.....
Li ₂ O.....	(e)	.....	.....
H ₂ O below 110°.....	.18	} 1.33	.....
H ₂ O above 110°.....	.43		.....
P ₂ O ₅	.20	.04	.....
V ₂ O ₅	Trace.	.55	.....
CO ₂	.12	.10	.....
S.....	.07	.14	.....
Fe.....	100.02	99.15	.....
Specific gravity.....	3.090	32.82	32.59
		4.138	

a Wall rock; analyst, W. F. Hillebrand.

b Ore; analyst, W. F. Hillebrand.

c Ore; analyst, G. W. Maynard.

d Not determined.

e Faint trace.

Analyses 1 and 2 have been recast by Prof. Kemp. Analysis 3 could not be recast on account of the great excess of Fe₂O₃ over FeO.

The mineralogical composition of Split Rock ore is presented below:

Mineralogical composition of Split Rock ore and gabbro.

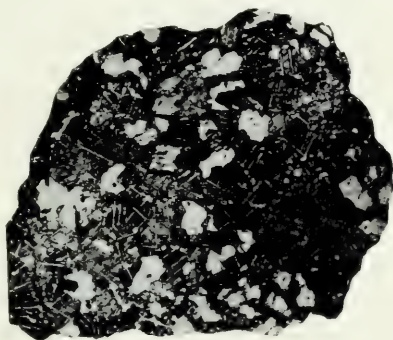
Constituent.	1	2
	<i>Per cent.</i>	<i>Per cent.</i>
Ilmenite.....	2.13	29.42
Magnetite.....	2.09	22.97
Pyrrhotite.....	.18	.35
Olivine.....	16.92	.....
Pyroxene.....	13.41	22.91
Plagioclase.....	56.70	13.62
Orthoclase.....	4.45	.....
Apatite.....	.34	.....
Calcite.....	.20	.....
Kaolin.....	3.10	.20
Water.....	.18	.....
NiO.CoO.....	.02	1.33
Spinel.....	.....	5.97
Corundum.....	.....	.92
V ₂ O.....	.....	.55
P ₂ O ₅.....	.....	.04



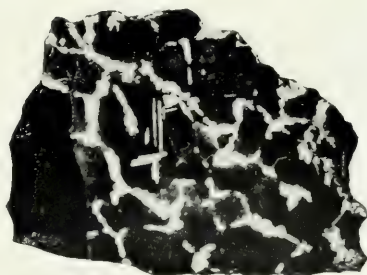
A. SPLIT ROCK, N. Y., ORE. (X 2.)



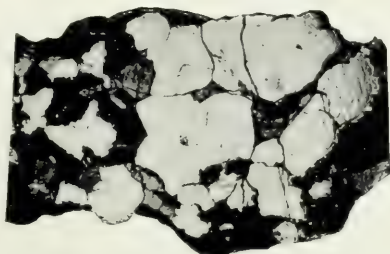
B. MILLPOND, N. Y., ORE. (X 2.)



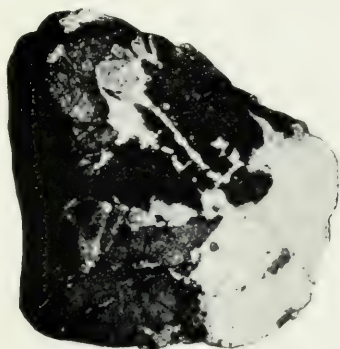
C. TUSCARORA MINE, N. C., ORE. (X 2.)



D. SHANTON RANCH, WYO., ORE (X 2.)



E. CEBOLLA CREEK, COLO., ORE. (X 2.)



F. CEBOLLA CREEK COLO., ORE (X 2.)

The percentage of the iron in the ore is very low and the ore would have to be concentrated before it could be used in the furnace. In that event 5.35 per cent of iron, present in the ferric minerals of the gangue, would be lost. It would also be desirable to eliminate as much of the ilmenite as possible, and this carries 10.84 per cent of iron. Only 16.63 per cent of iron is present in the form of magnetite, and so far as possible the concentrates should consist only of it. Notwithstanding the low grade of the ore an unsuccessful attempt was made to work it 30 or more years ago, when a dock was built at the foot of the hill and a small magnetic concentrator erected. The small size of the deposit and the leanness of the ore make the deposit of no value.

METALLOGRAPHIC DESCRIPTION OF ORE.

The ore grains in the lean ore range from 0.1 to 1 mm. in diameter and compose 20 to 50 per cent of the surface. Ilmenite grains are somewhat less abundant than magnetite. The magnetite contains comparatively few inclusions of ilmenite, and these are principally lamellæ, forming an open network structure.

The high-grade ore consists of coarser-grained aggregates of magnetite and ilmenite, ranging up to 3 mm. in diameter, and containing little gangue. The ratio between ilmenite and magnetite is about the same as in the leaner ore. The ilmenite intergrowths in the magnetite are much more abundant. These show in section a closely crowded network of 40 or more lines to a millimeter, as in Plate III, *A*, and a network made up of very short dashes. In much of the ore both types are present in the same magnetite grain and there may be a marked tendency for one series of lines to be more prominent and more fully developed than the others. The effect then is the same as that shown for the Little Pond ore in Plate III, *B*.

LITTLE POND MINES.

Two openings have been made in ore bodies near Little Pond, and 2 miles southeast of Elizabethtown. One opening, about a quarter of a mile north of Little Pond, is 20 by 20 feet and 15 feet deep; the other, lying about an eighth of a mile to the southeast, is run into a hillside about 30 feet and has a width of 30 feet and a working face 25 feet high. The country rock is the normal dark-green gabbro, the exposures of which are numerous in the vicinity. Besides the exposures of ore at the two pits, several others were seen in the neighborhood. The outcrops of gabbro between them show that the ore bodies are a number of small segregations, and not an entire hill of ore inexhaustible in amount as has been stated.

The ore is very similar in character to the Split Rock ore just described. Most of it is a fine-grained ore of seeming good quality, but polished sections show that it contains much gangue. A small

amount of coarser-grained high-grade ore also occurs. The ore also contains the green glass found in the Split Rock mine. The results of two analyses made by W. F. Hillebrand are taken from Kemp, as follows:

Results of analyses of Little Pond ore.

Constituent.	1 ^a	2 ^b
	<i>Per cent.</i>	<i>Per cent.</i>
TiO ₂	18.82	13.07
FeO.....	29.78	28.35
Fe ₂ O ₃	26.30	11.16
Cr ₂ O ₃	.75	.37
V ₂ O ₅	.62	.50
P ₂ O ₅	Trace.	.32
S.....	.06	.10
Fe.....	76.33	53.87
Specific gravity.....	41.57	29.87
	4.410	3.833

^a Represents ore from the north pit.

^b Represents ore from the south pit.

The analyses have been recast by Kemp, as follows:

Partial mineralogical composition of Little Pond ore.

Constituent.	1	2
	<i>Per cent.</i>	<i>Per cent.</i>
Ilmenite.....	35.27	24.49
Magnetite.....	38.05	16.24
Chromite.....	.64	.45
Pyrrhotite.....	.18	.26

METALLOGRAPHIC DESCRIPTION OF ORE.

The description given of the Split Rock ore can be applied to this ore with little modification. It averages a little coarser grained and the ilmenite intergrowths in the magnetite are not as closely packed. The more usual spacing is 8 to 15 lines per millimeter. There is also the tendency for one series of lines to be more prominent than the others. An interesting type is where one set of lamellæ are heavy and widely spaced, and the other two sets are made up principally of minute, closely crowded dashes. Such a structure is shown in Plate III, B.

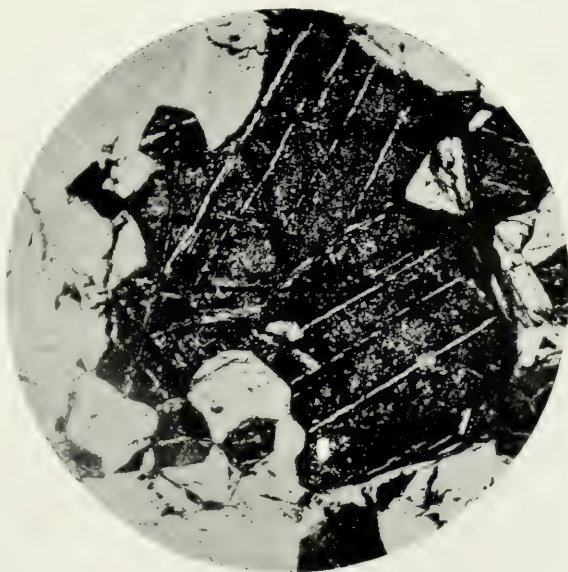
TUNNEL MOUNTAIN MINES.

The Tunnel Mountain mines are situated a mile to a mile and a half southeast of Little Pond, and 3½ miles southeast of Elizabethtown. Near the foot of the southeast side of the mountain are two small pits, about 200 yards apart, showing lean ore. Lack of exposures make it impossible to determine the extent of the deposits.

The largest opening occurs on the western edge of the extreme summit of the mountain, where a pit 40 feet long, 10 feet wide, and 40 to 50 feet deep has been made. Two hundred feet below the summit



A. SPLIT ROCK, N. Y., ORE. ($\times 60$.)



B. LITTLE POND, N. Y., ORE. ($\times 60$.)

and south of the pit an adit was commenced and run in about 100 or 150 feet. From this tunnel the mountain received its name. The ore body exposed here has a length of about 300 feet and a width of 100 feet. Beyond the exposure it passes over into the country rock. The latter is described by Kemp as a gneissoid norite with hypersthene the most prominent bisilicate. The other components are green augite, brown hornblende, plagioclase, and garnet. Thin sections of the ore reveal, besides the ore minerals, brown hornblende, serpentinized olivine, garnet, and colorless transparent labradorite.

The ore ranges from medium to fine grained, and like all ore of that kind appears richer in hand specimens than is actually the case. Polished specimens show the presence of a large amount of gangue. The following are the results of two analyses by W. F. Hillebrand, taken from Kemp:

Results of analyses of Tunnel Mountain ores.

Constituent.	1 ^a	2 ^b
	<i>Per cent.</i>	<i>Per cent.</i>
TiO ₂	16.45	10.55
FeO.....	28.82	21.34
Fe ₂ O ₃	20.35	11.52
SiO ₂	13.35	.....
Al ₂ O ₃	8.75	.....
Cr ₂ O ₃	.55	.25
CaO.....	2.15	.....
MgO.....	6.63	.....
V ₂ O ₅	.61	.34
P ₂ O ₅	.02	.46
S.....	.09	.10
H ₂ O.....	1.68	.....
CO ₂	.17	.....
C.....	Trace.	.....
Cl.....	Little.	.....
Fe.....	99.62	.....
	35.99	24.65

^a Represents ore from the deposit at the top of the mountain.

^b Represents ore from one of the pits near the foot of the mountain.

These analyses, recast by Kemp, are as follows:

Mineralogical composition of Tunnel Mountain ore.

Constituent.	1	2
	<i>Per cent.</i>	<i>Per cent.</i>
Ilmenite.....	30.80	25.344
Magnetite.....	29.80	16.704
Chromite.....	.64	.....
Anorthite.....	9.45	.....
Spinel.....	7.38	.....
Olivine.....	6.94	.....
Enstatite.....	11.40	.....
Calcite.....	.40	.....
Water.....	1.68	.....
Vanadic acid.....	.61	.....
Sulphur.....	.09	.....
Phosphorus.....	.02	.....
Residue SiO ₂	.36	.....
Remaining FeO.....	.....	6.912
	99.57	.....

METALLOGRAPHIC DESCRIPTION OF ORE.

Gangue constitutes from 25 to more than 50 per cent of the surface of the ore. The magnetite grains are about twice as abundant as the ilmenite, though in places the ilmenite is nearly as abundant as the magnetite. Few grains exceed $1\frac{1}{2}$ mm. in diameter. Regular intergrowths of ilmenite lamellæ in the magnetite are not very abundant, and where they do occur they form a very open structure and are rather thin. Many of the magnetite grains, on the other hand, are swarming with minute inclusions of ilmenite which at times show a tendency to orient along parallel lines, suggesting the incipient development of a network structure. This type of ilmenite inclusion is discussed more fully and illustrated in connection with the description of the metallographic features of the Minnesota ores.

LINCOLN POND MINE.

Three-quarters of a mile southwest of the road crossing the lower end of Lincoln Pond, and a quarter of a mile back from the pond, is an open cut into a steep cliff of gabbro, which is known as the Lincoln Pond or Kent mine. The location is 5 miles northwest of Mineville. The opening is 15 feet wide and nearly 100 feet long. At the far end a shaft was put down, but this is now filled with water, so that its depth could not be determined at the time of inspection. The opening shows little ore, the principal showing being on the left side at the far end. There is a gradual transition from gabbro to ore without any change in the size of the constituent mineral grains. Both ore and rock are fine grained. The rock is described by Kemp as varying from a true norite to a gabbro with accessory hypersthene. Garnet may or may not be present, and in some places is rather abundant. It assumes at times a peculiar fingerlike development in the plagioclase, a feature that has been noticed at other places in the Adirondack gabbros.

About 50 feet beyond this opening is a small opening in which is exposed high-grade coarse-grained ore resembling in appearance the ore in the anorthosites. The contact between this ore and the gabbro is sharp and lacking in a transitional zone.

The following results of analyses of wall rock and ore are available:

Results of analyses of Lincoln Pond ores and wall rock.

Constituent.	1 ^a	2 ^b	3 ^c	4 ^d
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
SiO ₂	44.77	11.73	4.73	.....
TiO ₂	5.26	12.31	2.58	5.88
Al ₂ O ₃	12.46	6.46	.....	.....
Fe ₂ O ₃	4.63	30.68	.....	.....
FeO.....	12.99	27.92	.....	.....
NiO.CoO.....	Trace.	(<i>e</i>)	.....	.....
MnO.....	.17	(<i>e</i>)	.05	.....
CaO.....	10.20	3.95	.....	.....
BaO.....	Trace.	.....	.....	.....
MgO.....	5.34	3.35	.....	.....
K ₂ O.....	.95	.26	.....	.....
Na ₂ O.....	2.47	.50	.....	.....
H ₂ O below 100°.....	.12	.....	.....	.....
H ₂ O above 100°.....	.48	.64	.....	.....
P ₂ O ₅	.28	.82	1.074	.....
V ₂ O ₅	(<i>e</i>)	.04	.....	.....
CO ₂	.37	.32	.....	.....
S.....	.26	.04	.272	.....
C.....	.....	.05	.....	.....
Cl.....	.....	.12	.....	.....
F.....	.....	Trace.	.....	.....
Fe.....	100.75	99.19	.....	.....
Specific gravity.....	3.090	44.19	59.26	64.66
		4.138	.....	.....

^a Represents wall rock. Analyst, George Steiger. (See Kemp, J. F., *The titaniferous iron ores of the Adirondacks*: 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 407.)

^b Represents ore. Analyst, W. F. Hillebrand. (See Kemp, J. F., *op. cit.*, p. 407.)

^c Represents ore. Figures furnished by W. L. Cumings of the Bethlehem Steel Co.

^d Represents coarse-grained high-grade ore taken from the small pit. Results were calculated from results of analyses by A. C. Fieldner, of the Bureau of Mines, of concentrates and tailings of a magnetic separation.

^e Not determined.

The high phosphorus content of the ore is noteworthy and is corroborated by the abundant apatite seen in thin sections. Another feature commented on by Kemp is the presence of carbon. Traces of carbon were found in the ores from some of the other localities, and in this case it amounts to 0.05 per cent. Hillebrand inferred the presence of graphite, though this could not be unquestionably established. Of the three ore analyses, analysis 2 alone represents the normal titaniferous ore in the gabbro. Its iron content is somewhat higher than the average for the region.

Analyses 1 and 2 have been recast by Kemp with the following results:

Mineralogical composition of Lincoln Pond gabbro and ore.

Constituent.	1	2
	<i>Per cent.</i>	<i>Per cent.</i>
Ilmenite.....	9.73	22.95
Magnetite.....	6.73	44.31
Pyrrhotite.....	.65	.09
Apatite.....	.67	1.74
Olivine.....	2.93	7.33
Pyroxene.....	32.71	5.01
Plagioclase.....	37.36	12.53
Orthoclase.....	5.00	.....
Kaolin.....	3.60	.....
Calcite.....	.90	.....
Spinel.....	.....	3.55

METALLOGRAPHIC DESCRIPTION OF ORE.

The fine-grained lean ore of this occurrence is similar to the ore from other occurrences of the region previously described. On the polished surfaces examined ilmenite intergrowths in the magnetite are not very abundant and consist chiefly of swarms of minute dots. Such line structure as is developed is caused by widely scattered lamellæ, so that the intersecting-line pattern is not prominent. The individual ore grains of the coarser ore reach a diameter of 5 mm. or even more in a few cases, but the average is between 2 and 3 mm. Gangue minerals are almost lacking. Polished sections of this ore differ decidedly in appearance from most coarse-grained titaniferous magnetites. Instead of the sharp contrast between the bright surfaces of the ilmenite grains and the dull faces of the magnetite most of the surface, on being etched, takes on an iron-gray to silver-gray color. Bright surfaces of ilmenite grains occur only sparingly. The duller grains of magnetite show an open-line structure in which the lines are not usually continuous, but are made up of a series of dashes as shown in Plate IV, A. This figure also shows the film of ilmenite that frequently outlines the magnetite grains. The more lustrous grains have the silvery, mottled appearance of nontitaniferous magnetites. They differ from such, however, in that in places this mottled effect loses its irregularity and takes on a linear arrangement. Hence the mottling may be due to minute ilmenite inclusions possessing no regular orientation.

The results of a magnetic separation and analysis of the products of a sample of the coarse ore bear out the above metallographic description of it. These results follow:

Results of magnetic concentration and analysis of Lincoln Pond ore.

	Un-screened ore.	Ore through 50-mesh, over 100-mesh. ^a		Magnetic ore through screen finer than 100-mesh. ^b
		Magnetic.	Non-magnetic.	
	Per cent.	Per cent.	Per cent.	Per cent.
Quantity.....		96	4	95.6
Fe.....	64.66	66.08	30.59	66.27
TiO ₂	5.88	4.82	31.45	5.12

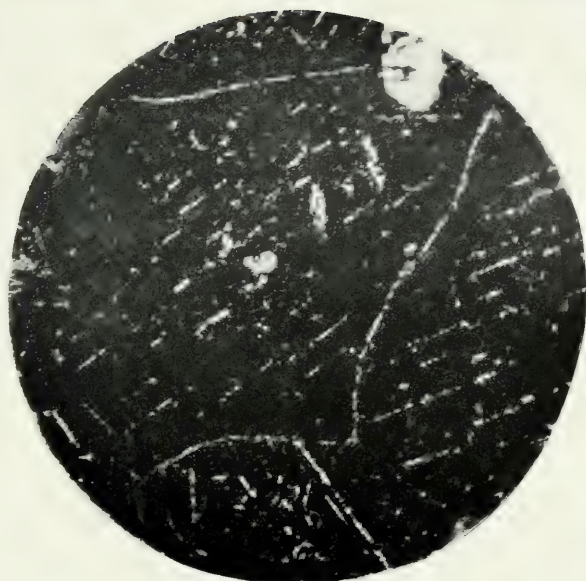
^a 46.9 per cent.

^b 53.1 per cent.

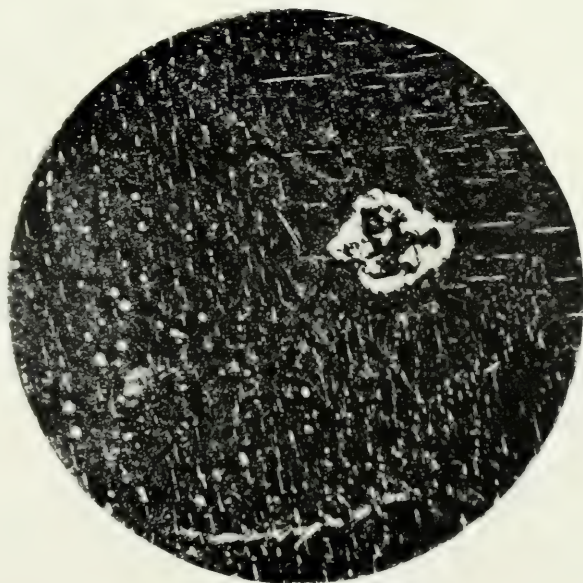
It is thus seen that the ore is low in titanium and that only 2.4 per cent of ilmenite was separable.

DALTON ORE.

A deposit known as the Dalton ore has recently been prospected by Witherbee, Sherman & Co. by means of diamond drilling and a



A. LINCOLN POND, N. Y., ORE. (X 60.)



B. MILLPOND, N. Y., ORE. (X 60.)

small pit. It is situated about 1 mile northwest of Feeder Pond and $5\frac{1}{2}$ miles west of Mineville, high up on the east slope of Ash Craft Brook. The pit is on the main ore body and is 20 by 10 feet by 5 feet deep. The relations of the ore bodies to the country rock are well exposed here and hence the deposit is of unusual interest. The country rock is a greenish gabbro with considerable dark, nearly black garnet. The garnet occurs in numerous small clusters producing a rock resembling the garnet-rich gabbro of the Split Rock mine. The ore outcrops occur within an area about 300 feet long parallel to the valley and 100 feet wide. At the southwest end of this area the gabbro is cut by a small pegmatite dike.

The ores are much richer than the average of the region and also differ in that there is no transition of gabbro into ore, so that the ore can not be considered an iron-rich phase of the gabbro, but it appears in distinct schlierenlike masses which seem to have been injected into their present position while the gabbro was still in a molten condition. The contact between the ore and the wall rock is marked by a distinct garnet-rich zone. The ores occur in narrow veinlets less than an inch in width, increasing in size to larger masses which, in the case of the main ore body, attain a width of 40 feet. The small veinlets are usually homogeneous in character and free from inclusions of country rock; the larger masses may have irregular outlines and also contain inclusions of country rock. The gabbro in the vicinity is much sheared and the ore tends to lie parallel to the schistosity, though some veins plainly cut across the schistosity.

The ore contains little gangue and this in some places is principally feldspar and at others principally femic minerals. It is about as coarse grained as the ore in the anorthosite, which it much resembles in the hand specimen. The following results of analyses, with the exception of the last, were furnished by Mr. Le Fevre of Witherbee, Sherman & Co. The results last given were furnished by W. L. Cumings of the Bethlehem Steel Co.:

Results of analyses of Dalton ore.

Constituent.	1		3	4	5		7
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	52.20	47.79	50.46	47.71	48.00	56.03	57.71
TiO ₂	7.12	7.53	11.47	5.62	7.58	7.72	3.90
P.....	.020	.042	.017	.026	.060	.014	.048
S.....							.022
SiO ₂							4.95
Mn.....							.07

The percentage of iron and titanium in this ore is similar to that of the coarse-grained Lincoln Pond ore. In megascopic appearance they are much alike. Though not as well exposed at Lincoln Pond as

here, it was noticed there also that the contact between rich ore and country rock was sharp and not transitional. Geologically the coarse-grained Lincoln Pond ore would seem to be identical with the Dalton ore.

METALLOGRAPHIC DESCRIPTION OF ORE.

The similarity of the Dalton ore and the coarse-grained Lincoln Pond ore in geologic occurrence, in appearance, and in composition is likewise shown in microstructure. Large grains of ilmenite are more abundant in the Dalton ore, but the appearance of the etched magnetite is nearly the same. Some of the duller magnetite grains show a tendency to rectilinear arrangement of ilmenite intergrowths which are not continuous lines but a series of dashes as illustrated in Plate IV, A. The triangular network is faintly developed in a few places. The greater part of the magnetite has the grayish, mottled appearance described in discussing the Lincoln Pond ore.

This ore and the coarse-grained Lincoln Pond ore differ from the other occurrences of the gabbro in this region in the relation of the ore to the wall rock, in the higher iron content and lower titanium content, and in the lack of distinctiveness of the ilmenite intergrowths in the magnetite. Their metallographic features suggest a close relation to the low-titanium ores in the syenite, such as occur at the Nigger Hill mine on the mountain northwest of Lincoln Pond.

POSSIBILITIES OF UTILIZING THE ORES IN THE GABBRO.

All of the deposits in the three townships just discussed occur in the gabbros, and with two exceptions show the same general characteristics. Further, these characteristics differ sufficiently from those of the ores in the anorthosite to make a separate discussion of their commercial possibilities necessary. As the ores in Newcomb Township, which are next described, occur principally in the anorthosite, the economic aspect of the ores in the gabbro is considered at this point.

The facts in regard to the individual deposits have been stated in the foregoing detailed descriptions. It is now desired to give a comprehensive statement of the possibilities of this class of ores considered as a whole. This phase of the question is so well presented by Kemp ^a that his opinion is quoted verbatim in the following paragraphs:

Enough analyses are now in hand to illustrate in a satisfactory manner what may be expected. The percentage in iron, titanic oxide, phosphorus, and sulphur may be first summarized with the name of the sampler.

^a Kemp, J. F., *Geology of the Elizabethtown and Port Henry quadrangles*: N. Y. State Mus. Bull. 138, 1910, pp. 147-149.

Results of analyses of ores from the Adirondack region.

Source of ore.	Sampler.	Fe.	TiO ₂ .	P.	S.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Split Rock.....	J. F. Kemp.....	32.82	15.66	0.017	0.14
Do.....	G. W. Maynard.....	32.59	14.70		
Tryan Pit.....	J. F. Kemp.....	24.65	10.55	.20	.10
Tunnel Mountain.....	do.....	35.99	16.42	.009	.09
Little Pond.....	do.....	41.57	18.82	Trace.	.06
Do.....	do.....	29.87	13.07	.14	.10
Lincoln Pond.....	do.....	44.19	12.31	.36	.04
Oak Hill.....	do.....	38.98	5.21	.06	.04
Kingdom Works.....	G. W. Maynard.....	32.59	13.15		
Iron Mountain.....	J. F. Kemp.....	40.42	16.37		

It is at once apparent that all of these ores are extremely low grade, the richest being 44.19 and only two others reaching 40. Since under present conditions and those which are likely to continue for many years no magnetite under 50 per cent in iron is of importance as a source of lump ore, unless it should have exceptional purity in phosphorus and sulphur, be lacking in titanium, and be in addition located near a furnace, there is little encouragement to look with favor upon bodies of this type.

The percentages in phosphorus and sulphur are also important features. In sulphur the ores are obviously low. In phosphorus they are variable. In instances such as Split Rock and Tunnel Mountain they are very low; in others they are quite high, as at Lincoln Pond. There is a somewhat widely prevalent impression that the titaniferous ores always run low in phosphorus and sulphur, but this is clearly unjustified. As with other ores each case must be sampled by itself.

The presence of vanadium in these ores is a matter of much scientific interest, and since the element has come into such extended use for high-grade steels some have looked to the titaniferous ores as possible sources. If we summarize the results given above, we obtain:

	V ₂ O ₅ .
Split Rock	0.55
Tryan Pit	.34
Tunnel Mountain	.61
Lincoln Pond	.62
Little Pond	.50
Do	.04

In just what form the vanadium is combined is unknown. From its chemical properties similar to phosphorus one would suspect some compound analogous to apatite, just as we have pyromorphite and vanadinite, but although the vanadic oxide exceeds in amount the phosphoric, the mineral containing it has never been isolated.

Ferrovandium is manufactured from vanadium compounds by electrical processes and contains about 25 to 27 per cent of this element. It would appear as if the percentage of this valuable substance were too low to make it a serious factor in the value of the ore, but as the industry of vanadium is as yet in its infancy one should speak regarding its future in a conservative spirit. In a vanadium steel now so highly prized for its toughness there is much less than 1 per cent vanadium. Elementary vanadium constitutes 77.4 per cent of vanadic oxide (V₂O₅).

Magnetic iron ores under 50 per cent and not fulfilling the conditions stated above must undergo magnetic concentration if they are to be utilized. It is with regard to this method of treatment that the recasting of the analyses into percentages of ilmenite and magnetite has especial significance. The magnetite would be the mineral saved and the one upon which efforts would be especially expended. The iron in the ilmenite we would expect, if not hope, to lose, so as to reduce the titanium. The iron

in the pyroxene and olivine would pass off in the nonmagnetic tailings. So far as iron is concerned we are therefore reduced to considering along the magnetite, and therefore the following tabular summary is presented:

Mineralogical composition of Adirondack ores.

Source of ore.	Ilmenite.	Magnetite.	Iron in magnetite.
Split Rock.....	29.42	22.97	16.63
Do.....	27.95	32.8	23.74
Tryan Pit.....	25.34	16.71	12.10
Tunnel Mountain.....	30.80	29.80	21.58
Little Pond.....	35.27	38.05	27.55
Do.....	24.49	16.24	11.76
Lincoln Pond.....	22.95	44.31	32.08
Oak Hill.....	9.70	44.08	31.91
Kingdom Works.....	24.64	31.08	22.50
Iron Mountain, Elizabethtown.....	30.80	35.73	25.86

These results show that even if the ilmenite and magnetite are so coarsely intergrown as to make a separation feasible the grade of the ore is too low to make the separation a likely source of profit. On the other hand, the ore is extremely hard and fine grained, quite different from the richer and more coarsely crystallized occurrences at Lake Sanford, and parallels can not be justly drawn. While the concentrates would doubtless be somewhat enriched in iron by ilmenite which would enter them, they would be decreased by some inevitable losses in magnetite, and by just so much as the titanium exceeded a very small value, say 1 per cent, the operators of iron furnaces under present slag calculations would regard them unfavorably.

The conclusion is quite irresistible that only by smelting in the crude or lump form, and by the development of a process which does not find titanium objectionable, and under conditions where ores of iron content of 35 to 45 could be utilized, can these deposits be made available.

That these ores hold out small economic possibilities for some time to come can be demonstrated by other considerations not mentioned above. With only one or two exceptions they are at present inaccessible to proper transportation facilities. To provide them with such would involve an expense that would be warranted only in connection with very large deposits. From the nature of the deposits there is no reason to expect the third dimension, or the extension in depth, to be any greater than the larger of the two surface dimensions. Wherever the areal extent of the deposits can be determined it is either small or, if large, its size is not due to the presence of a single large ore body, but to a series of small deposits, between which are areas of barren country rock. Adding to this difficulty the leanness of the ores, which makes the erecting of a concentrating plant necessary, and their titaniferous character, the hope of utilizing these ores within any reasonable period in the future is by no means bright.

DESCRIPTION OF OCCURRENCES IN NEWCOMB TOWNSHIP.

Several titaniferous ore bodies occur in this township, near the headwaters of the Hudson River, in the neighborhood of Henderson and Sanford Lakes. The position of these ore bodies is shown in

Plate V.^a They include the largest bodies of titaniferous iron ore in the Adirondacks, and one of them, the Sanford ore bed, is exceeded in size by only one other deposit in the United States, that of Iron Mountain, Wyo.

As this region was at one time the seat of the most extensive operations yet conducted on titaniferous ores in this country, a brief historical sketch taken from Newland ^b is of interest here. The sketch follows:

The site of the former Adirondack village (now occupied by the Tahawus Club), which was built by the early ironworkers, lies in the midst of a wild, heavily forested region, shut in by high elevations on all sides except the south, where the river has worn a narrow valley. North Creek, the terminus of the Adirondack branch of the Delaware & Hudson Railroad, is about 30 miles distant by wagon road, and Port Henry, on Lake Champlain, about 50 miles.

Unusual interest attaches to the events connected with the first developments of the Lake Sanford deposits and the establishment of the local iron-making enterprise to utilize the ores.^c Following the discovery, which is reported to have been made in 1826, a tract of land comprising the deposits was secured from the State by Mr. A. McIntyre and associates who soon after began active work. The investigations of Prof. Emmons in connection with the geological survey of New York then in progress no doubt gave a stimulus to the undertaking. Prof. Emmons published in his reports an extended account of the ore bodies, which he recognized to be of enormous size and regarded as eminently adapted to utilization. He recommended the location of iron-manufacturing enterprises in the vicinity. Soon after the publication of his first report, or about 1840, a blast furnace of 3 or 4 tons daily capacity was built and placed in operation. This was afterwards remodeled so as to enlarge its capacity, and a second furnace of 12 to 15 tons was put in blast in 1854. Drawings of the large stack, which remains to the present day, with all its essential features have been made by Mr. Rossi and published in the article already referred to. The installation included also puddling furnaces and the necessary equipment for making bar iron. The works were closed down in 1856, after which they were not again operated for any length of time. The product of the furnaces was hauled over a difficult mountain road to Crown Point for shipment, and the expense of transportation must have been a heavy tax upon the enterprise.

There seems to be little doubt, judging from all accounts, that the iron turned out in the early days was of good quality; in fact it was especially commended by Emmons and others; nor does it appear that the sudden termination of iron making was due to metallurgical difficulties in reducing the ore, though it is probable that the operators, at least in the early years, were unaware of the titaniferous character of the material. From considerations based on an analysis of slag, which was taken from the dump near the old furnace, Mr. Rossi has expressed the opinion that the furnace charges were made up on somewhat different lines than usually practiced in that a proportion of the country rock (anorthosite) was added to the limestone for flux. It may be noted, however, that the crude ore such as was employed in the operations contains more or less of admixed rock, so that the presence of the latter may have been accidental rather than intentional.

^a The map comprising this plate is a reproduction, with slight correction, of Plate 15 of N. Y. State Mus. Bull. 119.

^b Newland, D. H., *Geology of the Adirondack magnetic iron ores*: N. Y. State Mus. Bull. 119, pt. 3. 1908, pp. 155-156.

^c A good historical account of the discovery and exploitation of the deposits will be found in Watson's "History of Essex County." The reports by Emmons contain a description of developments up to 1840. For details as to the blast furnaces and metallurgical operations consult Rossi, "Titaniferous Ores in the Blast Furnace": *Trans. Am. Inst. Min. Eng.*, vol. 21, 1892-93.

After lying idle for 50 years the property was taken over in 1907 by a new organization * * * with a view to the exploitation of the ores. This company has conducted a thorough investigation and intends to enter upon active mining in the near future. The construction of a railroad is a requisite before commercial shipments can be made.

GENERAL FIELD RELATIONS.

The area under consideration lies within the main anorthosite area of the Adirondacks, near its western boundary. With one or two exceptions where the ore occurs in gabbros, the anorthosite forms the country rock of the deposits.

In its typical development, the anorthosite is a nearly pure plagioclase rock in which labradorite is the predominant feldspar. The texture of the rock is coarsely granitoid, and the length of the feldspar crystals may reach several inches. It is most commonly light blue in color, but at times it is yellow and even black. Usually little else than the feldspar can be recognized macroscopically. In thin section, however, augite, hypersthene, and magnetite are seen as accessory constituents in widely varying amounts. Magnetite and ilmenite are far less abundant in this rock than in the gabbros. The anorthosite has resisted crushing and mashing to a far greater extent than the gabbros, and gneissic varieties are not so common. Where crushing has taken place, garnet, biotite, and calcite are developed as secondary minerals. No results of analysis of the anorthosite of this area are available, but the analysis whose results are given below was made by Prof. Albert R. Leeds ^a of a sample taken from the summit of Mount Marcy.

Results of analysis of anorthosite from Mount Marcy.

Constituent.	Per cent.
SiO ₂	54.47
Al ₂ O ₃	26.45
Fe ₂ O ₃	1.30
FeO.....	.67
CaO.....	10.80
MgO.....	.69
Na ₂ O.....	4.37
K ₂ O.....	.92
Loss.....	.53

In a few places within the ore-bearing area the typical anorthosite gives way to a fine-grained rock in which the femic minerals are more abundant, forming a gradation to gabbro. This rock seems to have been less resistant to metamorphism and in many places shows a gneissic structure. In such cases it contains considerable hornblende derived from the pyroxene and much garnet. The rock is undoubtedly a phase of the anorthosite, but in some cases is not a differentiation in situ but has been intruded into its present position in the anorthosite in the form of dikes.



MAP OF THE VICINITY OF LAKE SANFORD, NEW YORK
ORE BODIES ARE INDICATED BY CROSS HATCHING

Scale $\frac{1}{62500}$
1 1/2 0 1 2 Miles

DESCRIPTION OF ORE DEPOSITS.

Ore occurs in both the anorthosite and the gabbro, but in this area the anorthosite is the more common wall rock. The ores in the gabbro are very similar to the ores in that rock in Westport, Elizabethtown, and Moriah Townships. Their geological occurrence and their chemical composition are about the same.

The ores in the anorthosite are of more uniform character and of higher grade in iron, and also coarser grained. The gradual transition from wall rock to ore so common in the gabbros is usually lacking. Anorthosite and ore are in most cases in sharp contact, with little if any increase in the amount of feric minerals in the anorthosite as the ore is approached. There seems to have been a complete differentiation of the ferruginous and titaniferous minerals on the one hand and the feldspathic on the other. In the one rock, iron oxide and titanium oxide crystallized by themselves; in the other, silica, alumina, soda, and lime. The intermediate feric silicates formed in small amount, a condition that Kemp suggests was due to the lack of magnesia. The ore carries a very small percentage of gangue, but in many places contains crystals of labradorite, which may attain considerable size. The feldspar is, however, never in actual contact with the ore minerals, but is separated from them by a narrow zone of fine-grained feric silicates. Further details in regard to the character of the deposits are given in the descriptions of the individual deposits.

DESCRIPTION OF DEPOSITS IN GABBRO.

CHENEY POND ORE.

The Cheney Pond deposit is situated near the south end of Cheney Pond, a little over a mile west of the road running along Sanford Lake. About 350 yards south of the lake is a pit 35 feet wide and 20 to 30 feet deep. Between this pit and the lake several diamond-drill holes were put in a few years ago. The cores of the drill supply information not otherwise obtainable on account of the lack of fresh rock exposures.

The rock is a gabbro gneiss which is very crumbly on weathered surfaces. Garnet and magnetite are prominent constituents throughout the rock. With increasing amounts of magnetite the rock grades over into ore. A thin section of the average grade of ore shows the ore minerals and plagioclase as the most abundant constituents, with the ore minerals forming about 50 per cent of the rock. Augite and garnet are also prominent. Less abundant are biotite, apatite, and dark-green spinel. The garnet and pyroxene tend to occur around the periphery of the feldspar crystals. Frequently the augite is replaced to a great extent by hornblende. Though most

of the ore is rather lean, there is a little high-grade ore in which there is only a small amount of gangue. The drill cores show that the gabbro grades over into anorthositic rock, so that at this locality the gabbro is merely a basic phase of the anorthosite and not an intrusive dike.

The results of two analyses of the ore from the pit have been published. One of these represents the average lean ore; the other must have been made from a sample of the richer phase and does not represent the run of these deposits.

Results of analyses of Cheney pit ore.

Constituent.	1	2
	<i>Per cent.</i>	<i>Per cent.</i>
TiO ₂	8.25	15.77
Fe ₂ O ₄	86.53	55.64
SiO ₂		9.79
Al ₂ O ₃		7.12
CaO.....		8.89
MgO.....		3.00
P.....	.39	
S.....	.74	1.00
Fe.....	62.15	40.33

The second analysis represents about the same composition as the ores in the gabbro in the townships to the east described on preceding pages.

Metallographic description of ore.—The microscopic structure of the ore presents little of interest. The size of the grain is roughly proportional to the richness of the ore. In the higher grade ores, ilmenite and magnetite grains attain dimensions of 4 mm.; in the leaner ores they scarcely reach 2 mm. and average considerably less. The ratio of ilmenite to magnetite is variable; some sections show nearly all ilmenite, others only a small amount. The average of all the sections examined shows the ilmenite somewhat in excess of the magnetite.

A surprising feature of the magnetite is the almost entire absence of ilmenite lamellæ intergrown in it. Only here and there was a line or two seen in the magnetite. On the other hand the swarms of minute ilmenite particles possessing no regular orientation and giving the magnetite a gray, mottled appearance are abundant. Besides these there occur large circular dots in dull magnetite grains.

On the whole what has been said regarding the possibilities of utilizing the ores in the gabbro applies to this deposit, except that it seems to be considerably larger than the average.

OTHER OCCURRENCES IN GABBRO.

Exposures of iron ore in fine-grained gabbro occur along Calamity Brook for some distance above its mouth. The ore is first encountered about 200 feet above the mouth of the stream on the north side,

where it plainly cuts the anorthosite. About 100 feet above this point another dike cuts across the brook in a northeasterly direction. For two or three hundred yards there is an alternation of this fine-grained rock and anorthosite. In places the contact between the two is a straight line, in others the boundary is irregular. In either case, however, the boundary is usually sharp and lacking in a transitional zone. At some of these contacts the evidence that they are intrusive is unmistakable. The rock is characterized by an abundance of magnetite and ilmenite and by the small amount of feldspar that it contains. Considerable pyrite is also present. A thin section of a richer phase of the rock shows besides the ore minerals augite and hypersthene as the most prominent constituents, a little biotite and spinel being noticeable. Locally the ore minerals become abundant enough to consider the rock a lean ore. On account of the fine grain and the lack of salic minerals, the rock has a black appearance which makes it look to be much richer than it really is.

The occurrence one mile east of the Tahawus Club, high up on the mountain slope, is more like the Cheney Pond ore in that it carries considerable plagioclase.

Some of the ore on the north side of the Hudson River between the bend and Lake Henderson is fine grained and lean, due to the presence of abundant femic minerals. This is especially so toward the west end of the ore-bearing area. Some of the drill cores show an alternation of fine-grained lean ore and coarse-grained high-grade ore. The following section of one of these cores is given by Newland:^a

Section from diamond-drill core from bore hole on north side of the Hudson River near Lake Henderson.

	Ft.	in.
Lean ore, consisting of disseminated magnetite with feldspar and pyroxene..	19	3
Rich ore.....	30	6
Rock and lean ore, alternating.....	15	..
Rich ore.....	33	6
Rock carrying some ore.....	11	1
Lean ore.....	12	..
Rock and lean ore.....	8	..
Rich ore alternating with seams of rock.....	10	7
Rock.....	5	..
	144	11

Though not so stated, what is called lean ore in this record is doubtless of the fine-grained gabbroitic variety.

DESCRIPTION OF ORES IN ANORTHOSITE.

The ores in the anorthosite attain their chief development along the Hudson River between the Tahawus Club and Henderson Lake

^a Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908, p. 162.

and on the west side of Sanford Hill overlooking Sanford Lake. The former area was the principal source of ore for the early iron works operated here, and the pit from which the ore was taken is called the Millpond pit.

MILLPOND ORE.

The Millpond pit is on the west side of the river directly opposite the mouth of Calamity Brook. It is an opening about 100 feet long and 12 to 40 feet wide, now filled with water. The lower part of the walls of the opening just above the level of the water shows a coarse-grained high-grade ore, nearly free from visible gangue minerals. The upper part of the walls around the rim of the opening consists of typical anorthosite. The contact between the two is, therefore, well exposed. The boundary is irregular in its outline, but sharp. Pure ore usually extends up to the very contact. The anorthosite at times contains small patches of ore surrounded by reaction rims. The intermingling, however, is by no means sufficient to suggest a transition from ore to wall rock.

The reaction rims between the feldspar and the magnetite are most beautifully developed both around feldspar inclusions in the ore and around ore inclusions in the feldspar in this area and on Sanford Hill. The nature of the rims varies considerably. A thin section from the Millpond pit showed a well-developed three-zone reaction rim. The large feldspar crystals swarmed with minute green spinels and acicular pyroxenes to such an extent as to render the feldspar so cloudy that the twinning bands are nearly obscured. Around this nucleus is a zone consisting of clear feldspar, pyroxene, and larger spinel individuals. The feldspar and pyroxenes occur as a matrix inclosing the abundant spinel. The second zone consists of a clear monoclinic pyroxene with very faint greenish tinge. Along fracture and cleavage lines a small amount of magnetite occurs. The third zone consists of a pyroxene of a darker green color, the fractures of which are heavily filled with magnetite. Beyond this zone is the magnetite. The width of the rim where the three zones are best developed is 1 mm.; where it becomes wider the zones lose their distinctness.

Another thin section from a specimen across the river from the Millpond pit showed a different development, though it, too, had three distinct zones. The feldspar is likewise clouded by minute inclusions, but running through it in long fingerlike and vermicular shapes are garnet crystals. The feldspar immediately adjacent to the garnet and, where the garnet had developed abundantly, whole areas of it are perfectly clear, indicating that the garnet is the product of a reaction between the feldspar and the minute inclusions. Surrounding these nuclei of feldspar is always a zone of clear feldspar and garnet. Next comes a narrow zone of clear feldspar nearly

free from any other minerals. In the third zone feldspar is nearly lacking, and the principal minerals are augite, biotite, and chlorite. Beyond this zone is the magnetite, which contains abundant inclusions of dark-green spinel. As in the previous case, the zones are most distinct where the reaction rim is not too wide.

Surface exposures of the ore do not indicate as extensive an area as shown by Newland (Pl. V). Fifty feet west of the Millpond pit is an exposure of anorthosite that is practically continuous to the top of the small knoll between the river and Henderson Lake. It may be that Newland's boundary is based on magnetic surveys. At the Millpond pit the ore is overlain by anorthosite, and it is quite possible that the ore body continues westward under the knoll of anorthosite.

The "Iron Dam" is a riffle across the river a short distance below the Millpond pit, on the surface of which considerable ore is exposed. The ore is of the same coarse-grained character as that of the Millpond pit, but large feldspar phenocrysts are more abundant. It occurs in the form of several larger lenticular bodies and numerous small stringers running through the anorthosite. The relations at the contact of ore and country rock are the same as those described as existing at the Millpond pit. On the east side of the river, between Calamity Brook and the sharp bend above it, are numerous exposures; most of them are of anorthosite. At several places, however, the anorthosite contains small lenticular and irregular shaped ore bodies and stringers of high-grade coarse-grained ore, exhibiting the same relations as the similar occurrences at the "Iron Dam."

The contact between the ore and the wall rock is exposed so often and so well at the localities just described that one can not help trying to picture to himself just how the ore came into its present position. In the processes of magmatic differentiation, as one ordinarily thinks of them, there is a gradual localization of certain constituents of the magma until a product is produced characterized by the predominance of those constituents. With increasing distance from such a differentiated mass, those constituents should more and more decrease and the remaining constituents increase in quantity until the average composition of the magma is again obtained. This change may take place rapidly, or it may take place slowly. One has the feeling, however, that such a transition should exist. In looking at these exposures no such picture is suggested. If a differentiation has taken place, it has been complete. One can put his finger on almost any point along the contact and say this is ore or this is anorthosite. It is difficult to get away from the suggestion that the ore has been injected into the anorthosite. Yet the irregular form of some of the ore bodies, and the numerous stringers running through the anorthosite in all directions present difficulties to explain. To have afforded passages for such irregular injections, the anorthosite must have undergone a certain amount of crushing and shattering.

That view would place the time of ore injection sufficiently later than the intrusion of the anorthosite to have enabled the latter to solidify and then be subjected to a certain amount of metamorphism. But even such a conception does not seem in accord with the phenomena observed. One would then expect to find somewhat angular and ragged boundaries, whereas the details of the boundaries are smooth and rounded. The only conclusion that is at all satisfying is that the ore came into its present position while the anorthosite was still in a viscous condition. Differentiation of the magma took place, producing a very feldspathic rock and a very pure iron ore. Compared with the degree of differentiation in the case of the ores in the gabbro, it was remarkably complete. The suggestion of Kemp that it was due to the lack of magnesium seems a very plausible explanation, as certain it is, not only here but elsewhere, that the iron ores in anorthosite are uniformly of higher grade than those in gabbro. It would seem that a gabbroitic magma poor in magnesia can differentiate to a greater degree than one rich in magnesia. The differentiated iron mass thus produced instead of solidifying completely in situ, was squeezed, at least in part, into other parts of the still fluid anorthosite. The relations at the contact are what one would expect if such were the processes involved. This is offered merely as a plausible explanation of the phenomena observed in this vicinity. Unfortunately the contacts of the larger ore body on Sanford Hill are not exposed, so that no comparisons can be made between the two areas. The intrusive character of the titaniferous magnetite in the anorthosite of Iron Mountain and Shanton ranch, Wyoming, is beyond question. A study of the relation at the contact of ore and wall rock of the Canadian and other foreign occurrences of titaniferous magnetite in anorthosite would be of considerable interest and scientific importance.

Opposite the Millpond pit and west of the bend in the river is a large area which has recently been prospected by trenching and diamond drilling. Ore has been shown to exist in a nearly continuous body over an area the boundaries of which have not yet been determined. It is not, however, all high-grade coarse ore such as is exposed in the Millpond pit. As stated previously, much of it is fine-grained lean ore resembling the ore found in gabbro. The diamond-drill cores also show the presence of considerable country rock, some of which is basic in appearance.

The ore consists almost entirely of magnetite and ilmenite, with little visible gangue. Here and there are large phenocrysts of green feldspar surrounded by the reaction rims already described. The coarse texture of the ore is distinctive; the grains have a mean diameter of 5 to 10 mm. In this respect the ore resembles the nontitaniferous magnetites of the Adirondacks. The two ores could never be

mistaken, however, as the titaniferous has a peculiar mottled luster due to the difference in luster of the magnetite and the ilmenite. The luster, however, is quite different from that of the nontitaniferous magnetites.

In the table of analyses given below, analyses 1 to 6 represent ore from the Millpond pit and are taken from Kemp, with the exception of 6, which was calculated from analyses of concentrates and tailings made by A. C. Fieldner of the Bureau of Mines; analysis 7 represents ore from the "Iron Dam" and is taken from Newland.

Results of analyses of Millpond ore.

Constituent.	1	2	3	4	5	6	7
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
TiO ₂	10.73	13.88	19.74	20.24	20.49	18.20	10.85
Fe ₂ O ₃	87.20	82.37	73.62	.....	.....	.....	.....
SiO ₂	1.09	3.67	1.53	.....	.91	.....	1.96
Al ₂ O ₃	.44	1.50	3.50	.....	.....	.....	.....
Mn ₂ O ₃	.13	.....	.....	.....	.....	.....	.....
CaO.....	Trace.	Little.	Little.	.....	.....	.....	.....
MgO.....	Trace.	.50	1.60	.....	.....	.....	.....
P.....	None.	.017	.037	.....	.....	.....	.008
S.....	None.	.068	.08	.....	.....	.....	.009
Fe.....	63.45	59.56	53.62	55.62	54.80	54.47	64.47

The average Fe content of these analyses is 58 per cent and the average TiO₂ content 16.3 per cent. Calculating the TiO₂ in terms of ilmenite and the remaining iron as magnetite, we have as the partial mineralogical composition of the ore 30.97 per cent ilmenite and 64.34 per cent magnetite, a total of 95.21 per cent. This computation brings out clearly the high grade of the ore. Phosphorus is below the Bessemer limit, and sulphur is low.

Metallographic description of ore.—The coarse texture of the ore has already been commented upon. As a result of this texture, there are very few grains below 1 mm. in diameter. The amount of ilmenite is always subordinate to that of magnetite, and varies from less than one-tenth to about one-third. Plate II, *B*, shows the usual relations between the magnetite and the ilmenite grains. The plate shows an etched polished surface of the ore free from visible gangue minerals.

The ilmenite intergrowths in the magnetite show considerable variety, though on the whole they are not very abundant. The magnetite usually etches to a dull black. The gray mottled effects, which in several cases have been shown to be due to the magnetite swarming with irregular particles of ilmenite, are not abundant. This is as one would expect in a coarse-grained ore, as the crystallization must have been slow enough to have given an opportunity to such inclusions to take on definite shapes and orientation.

One of the commonest forms of inclusions shows on the polished section as dots which are scattered over the surface in varying amounts. In places they occur rather sparsely; elsewhere the surface may be thickly covered with them. Where most abundant, they are usually of minute size. They differ from the swarms of minute particles mentioned in the preceding paragraph in that they have distinct, somewhat circular outlines, whereas the latter have indistinct, hazy outlines. Some of the dots attain considerably larger size and reach a diameter of 0.05 mm. The minute dots in such unusual abundance as to produce a clouded effect are seen in Plate IV, *B*. Interspersed among these are also some of the larger sized dots.

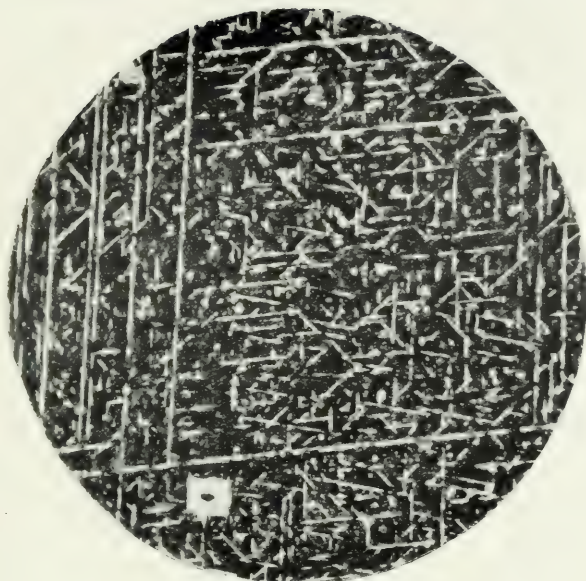
Less abundant, yet prominent, are the tabular intergrowths. More commonly the individual lamellæ are rather short, and where a number occur in the same plane the polished section shows a broken line. The lamellæ may occur isolated, and in such cases often become thicker in proportion to their length than the average. When abundant they take on the regular parallel rectilinear arrangement, producing a one-line, two-line, or three-line intersecting pattern according to the orientation of the section. This broken-line pattern is shown in Plate IV, *B*. The lamellæ are not, however, always short, but attain a length of 1 to 2 mm. and even more in places, producing a continuous-line pattern. Plate VI, *A*, shows a number of these larger lamellæ. The section is also of considerable interest in that it shows the magnetite to be twinned. If examined closely, it will be seen that instead of three series of intersecting lines corresponding to the octahedral cleavage of magnetite there are five series. They correspond to the cleavage of a twin about the octahedral face, and are either four or five in number according to the orientation of the section.

Another feature of many of the sections is the occurrence of a narrow rim of ilmenite about the outlines of the magnetite grains. This phenomenon was already noted in the case of the Lincoln Pond ore (Pl. IV, *A*).

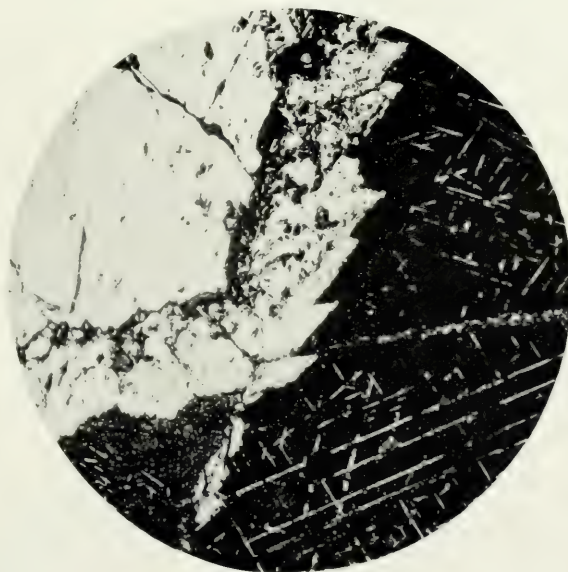
In many places a much coarser form of inclusion than those just described occurs around the ilmenite grains. It is in the form of a zone made up of irregular particles of ilmenite with their longer direction at right angles to the ilmenite border. Locally these particles coalesce, forming a continuous band. There is always a narrow strip of magnetite between the ilmenite grain and this zone. In a few cases the zone completely encircles the ilmenite grain, but usually it is discontinuous. This effect is shown in Plate VI, *B*.

SANFORD HILL ORE.

The Sanford Hill ore is the largest and most important body of titaniferous ore in the Adirondacks. It occurs on the west slope of



A. IRON DAM, N. Y., ORE. ($\times 60$.)



B. IRON DAM, N. Y., ORE. ($\times 60$.)

Sanford Hill overlooking Sanford Lake. Lack of exposures makes impossible the determination of the limits of the ore body. Diamond drilling during the years 1906 and 1907 has demonstrated that the ore continues practically to the lake. Magnetic surveys show lines of attraction that cross the lake and merge with the small ore body on the western shore below Big Island (Pl. V). It may be that the ore continues under the lake to the western shore. On the east, anorthosite is encountered before the summit of the hill is reached, and the summit itself is composed of anorthosite. The lateral extent, parallel to the lake, has not been determined, but is stated by Newland to be at least a half mile. Drilling has proved its continuance in depth to 300 or 400 feet, the maximum depth reached by the drill.

This part of the hill was laid bare at the time the drilling was done preparatory to commencing stripping, and a few trenches were made. Besides these there is an old opening on the hillside with a working face about 30 feet long and 15 feet high.

The anorthosite exposed on the east side of the deposit is very gneissoid. The feldspar is nearly white and running through it are black bands which in thin section are seen to be composed of dark-green hornblende. Smaller particles of the hornblende are scattered through the feldspar. Anorthosite is also scattered within the boundaries of the ore body. It seems to be segregated along certain bands and could easily be sorted in mining so as not to impair the quality of the ore. A thin section of the rock showed a small amount of augite that has to a great extent altered to hornblende.

In the early forties the deposit was prospected with considerable care by Prof. Emmons, for whom a number of pits were made to expose the ore. These pits have since filled up and their exact locations are not known, but the details of the observations are still valuable in that they show the manner in which the ore and the country rock are intercalated. The most detailed of the sections across the ore body made by Prof. Emmons is here reproduced as given by Newland.^a

Record of the middle transverse section of the Sanford Hill ore body.

Pit No.	Interval.	Remarks.
	<i>Feet.</i>	
1	.....	Fine granular feldspar, intermixed with iron, garnet, and hornblende.
2	36	Rich ore breaking into tabular masses.
3	10	Do.
4	15	Rich ore.
5	20	Rich ore, mixed in a small proportion with granular feldspar.
6	12	Granular feldspar in a decomposing state containing only a small proportion of ore.
7	20	Rich ore, mixed with a few scales of black mica and feldspar.
8	22	Rich ore, mixed with garnet and feldspar.
9	24	Nearly the same as No. 8, but brighter.
10	24	Rich ore with a very small proportion of feldspar.

^aNewland, D. H., *Geology of the Adirondack magnetic iron ores*; N. Y. State Mus. Bull. 119, pt. 3. 1908, pp. 159-160.

Record of the middle transverse section of the Sanford Hill ore body—Continued.

Pit No.	Interval.	Remarks.
	<i>Feet.</i>	
11	22	Loose decomposed rock.
12	17	Rich ore.
13	15	Rich ore, with feldspar.
14	39	Rich granular ore, with a resinous luster.
15	15	Lean ore.
16	22	Principally rock.
17	28	Pure ore.
18	35	Do.
19	36	Rich ore.
20	22	Pure ore.
21	27	Do.
22	30	Do.
23	29	Do.
24	30	Ore mixed with garnet.
25	14	Rock mixed with particles of ore.

On the basis of his explorations, Prof. Emmons estimated the ore body to contain 6,830,000 tons, at a depth of 2 feet below the adjoining surface. Besides being a very large deposit, it is well situated for mining, as its topographic position on the side of the hill makes open-quarry methods applicable.

The ore is identical in character with that at the Millpond pit. At the old opening it contains many large phenocrysts of green feldspar, which attain a length of 6 cm. and more. These are always surrounded by a reaction rim in which a golden-brown biotite is a prominent constituent. In thin section the feldspar is clouded by the minute inclusions described in the feldspar at the Millpond pit. Surrounding it is a narrow zone of clear feldspar with larger green inclusions, many of which are spinels. Then comes a broader zone of femic minerals, of which the most abundant are brown mica and hornblende. Less abundant is a nearly colorless augite. Beyond this zone is the magnetite.

In the following table of analyses, analyses 1 to 5 are quoted from Kemp and 6 and 7 from Newland, by whom the original sources are acknowledged. Analysis 8 was calculated from analyses of concentrates and tailings made by A. C. Fieldner of the Bureau of Mines.

Results of analyses of Sanford Hill ore.

Constituent.	1	2	3	4	5	6	7	8
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
TiO ₂	10.91	20.03	19.52	18.70	14.32	9.45	14.0	19.02
Fe ₂ O ₄	87.60	70.73	70.80	71.03	.....	.....	83.4	.....
SiO ₂	.87	2.46	1.39	1.34	1.39	2.09	.....	.....
Al ₂ O ₃	.53	3.50	4.00	.....	5.81	.....	.....	.....
P.....	.....	.....	.022	.....	.....	.007	.....	.....
S.....	.....	.....	.028	.....	.....	.027	.....	.....
Fe.....	62.65	51.22	51.30	51.44	56.60	63.36	60.5	55.07

In these analyses the average percentage of Fe is 56.52 per cent and of TiO_2 15.77 per cent. Computing the TiO_2 in terms of ilmenite and the remaining iron as magnetite we get 29.96 per cent ilmenite and 62.81 per cent magnetite in the ore, a total of 92.77 per cent. The composition is almost identical with that of the average of the Millpond ore. The two determinations for phosphorus show the content of that element to be below the Bessemer limit; the sulphur content is also low.

Metallographic description of ore.—The microstructure of the Sanford Hill ore is identical with that of the Millpond ore. The same types of intergrowth are found in this ore, and it is therefore useless to repeat the descriptions of them at this point. The only difference, if any, is that the intergrowths of ilmenite in the magnetite are somewhat less abundant in the Sanford Hill ore.

POSSIBILITIES OF UTILIZING THE ORES IN ANORTHOSITE.

The far greater size of the deposits, the much higher iron content, and the coarser texture of the ores in anorthosite make them far more attractive from a commercial standpoint than the ores found in the gabbro. Transportation facilities would have long since been provided if there had been any feeling of certainty that the difficulties caused by the presence of titanium could be overcome. Numerous experiments have been made to separate the titanium from the ore by means of magnetic separation, and the results of some of them are given below.

Kemp ^a gives the following results of analysis of concentrates and tailings of a magnetic separation of the Sanford Hill ore:

Results of magnetic separation of Sanford ore.

Constituent.	Concentrates.	Tailings.
	<i>Per cent.</i>	<i>Per cent.</i>
TiO_2	4.00	47.50
Fe.....	62.66	36.86

No statement is made as to the size to which the ore was crushed nor of the ratio between concentrates and tailings. If we assume the average composition of the Sanford Hill ore as the composition of the sample tested, the ratio of concentrates and tailings can be calculated. On the iron basis the tailings constitute 25.9 per cent of the original ore, and on the titanium basis 27.7 per cent. The agreement is so close that the mean 26.8 per cent may be assumed to be the amount of the tailings.

^a Kemp, J. F., *The titaniferous iron ores of the Adirondacks*: 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 416.

The possibilities of magnetic separation of the Sanford Hill ore are also discussed by Newland,^a whose statements are next given, as follows:

A partial separation of the magnetite and ilmenite was obtained with the ore from the Sanford pit at Lake Sanford. A sample was crushed through a 40-mesh sieve and the magnetite removed with a small hand magnet. The results from chemical analysis of the crude ore (1), magnetite concentrate (2), and the ilmenite and other residual minerals (3) are given herewith. The analyses were made by E. W. Morley.

Results of analyses of Sanford pit ore.

Constituent.	1	2	3
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe ₂ O ₃	55.9	54.39	14.28
FeO.....	27.5	28.66	30.93
TiO ₂	14	8.93	45.23

It will be observed that the magnetite concentrate still contains a considerable proportion of titanium, mostly due, no doubt, to the inclusion of particles of mixed character. By crushing still finer a cleaner separation may be made, as has been demonstrated * * *. The analyses are not reducible to simple terms of magnetite and ilmenite, and further work is needed before the chemical relations can be fully stated. It is quite likely that the magnetite itself carries a proportion of the titanium, in which case the entire removal of the latter would be impossible.

Another feature which may promote the use of the ores from that locality is their amenability to concentration, whereby the titanium can be reduced by at least a third of the total or to less than 6 per cent probably as a maximum limit. To the courtesy of F. E. Bachman, general manager of the Northern Iron Co., the writer is indebted for information concerning an experimental run made upon Lake Sanford ores at the Mineville magnetic concentrating plant within the past year. A 40-ton sample was passed through one of the mills and the concentrates showed the following percentages: Fe, 60.60 per cent; TiO₂, 9.66 per cent (equivalent to 5.8 per cent Ti). The tailings from the treatment gave: Fe, 42.84 per cent; TiO₂, 32.22 per cent. A sample of the concentrates recrushed so as to pass through a 16-mesh screen and reconcentrated by hand showed the following percentages on analysis:

Fe.....	63
SiO ₂	1.08
TiO ₂	5.25
Al ₂ O ₃	5.65

Another sample was crushed through a 40-mesh screen and subjected to separation under water with a hand magnet. Analyses of the concentrates are given below. No. 1 is by A. S. McCreath & Son and No. 2 by P. W. Shimer.

Results of two analyses of Lake Sanford ore.

Constituent.	1	2
	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	65.35	64.09
Mn.....	.186	
SiO ₂	.14	
TiO ₂	5.32	6.49
Al ₂ O ₃	2.76	2.59
CaO.....	.05	
MgO.....	.76	
P.....	.012	.0045
S.....	.041	

^a Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908 pp. 152, 154-155.

While it would scarcely be practicable, perhaps, to crush the ore to a size that would permit a reduction of the titanium to the limits indicated in the last analyses, there would appear to be no difficulty in the way of preparing concentrates with an average of 8 or 10 per cent TiO_2 . The loss of iron in the tailings is the only drawback to concentration, but in the case of immense deposits like those at Lake Sanford, which can be worked very cheaply, this could hardly be critical.

In none of the above cases is the ratio of tailings to concentrates given. In the case of the 40-ton sample, however, a ratio can be calculated by again assuming the original ore to have had the average composition of the Sanford ore, an assumption that, in view of the large quantity used, is fair. On the iron basis the tailings constituted 23 per cent of the original ore and on the titanium basis 27 per cent. The mean of these, 25 per cent, should be nearly correct.

Two separations made by the author, one on Sanford Hill ore and one on Millpond ore, did not give results as favorable as those above. The analyses of the tailings and concentrates were made by A. C. Fieldner, of the Bureau of Mines. The results follow:

Results of magnetic separation of Sanford Hill ore.

	Un-screened ore.	Ore through 50-mesh, over 100-mesh. ^a		Ore through screen finer than 100-mesh. ^b
		Magnetic.	Non-magnetic.	Magnetic.
	Per cent.	Per cent.	Per cent.	Per cent.
Quantity.....		78.2	21.8	75.9
Fe.....	55.07	61.23	32.99	61.23
TiO ₂	19.02	11.15	47.20	10.47

^a 47 per cent.

^b 53 per cent.

Results of magnetic separation of Millpond ore.

	Un-screened ore.	Ore through 50-mesh, over 100-mesh.		Ore through screen finer than 100-mesh.
		Magnetic.	Non-magnetic.	Magnetic.
	Per cent.	Per cent.	Per cent.	Per cent.
Quantity.....		83.2	16.8	85.3
Fe.....	54.47	58.89	32.74	59.17
TiO ₂	18.20	13.18	43.03	12.28

A sample was also prepared from the Sanford Hill ore by picking small pieces of magnetite from the surface of etched polished sections. As far as possible only such pieces were taken as were free from all visible intergrowths of ilmenite. The sample was further tested with

a magnet to make sure that it contained no nonmagnetic particles. The analysis of this sample made by A. C. Fieldner is as follows:

Fe.....	61.04
TiO ₂	11.00

From the manner in which this sample was prepared, the analysis results given ought to represent the most favorable results obtainable.

In the first two separations made by the writer the percentage of titanium was reduced by 41.4 and 27.6 per cent, respectively. If we assume in the third case the average composition of the Sanford Hill ore, the reduction was 30.3 per cent. The average of the three is 31.1 per cent, which accords with Newland's estimate that the titanium content can be reduced by a third.

The result obtained in the test at the Mineville magnetic-concentrating plant represents, therefore, the maximum separation obtainable; and the average of a long run of the ores is not likely to fall far behind this. A conservative statement of the results obtainable by magnetic separation is that concentrates can be produced running about 60 per cent Fe, less than 7 per cent Ti, low in sulphur, and far below the Bessemer limit in phosphorus, with a loss of not more than 25 per cent in the tailings. Aside from the titanium content, this is a most desirable product for the blast furnace. By mixing these concentrates with other ores in a ratio between 1 to 2 and 1 to 3, the titanium content can be brought down to 2 per cent, a quantity that would cause no trouble in the furnace. The size and situation of the deposit with reference to easy mining methods are such that, with transportation facilities provided, the concentrates could profitably be put on the market at the current prices. Of course the prejudice against titaniferous ores would retard and probably make impossible the sale of the ores if put on the market by an independent operator. There is no reason, however, why the deposits should not be worked by interests that control their own furnaces, and it is doubtless a question of only a few years before mining will have been begun on these ores.

NEW JERSEY.

Magnetite ores occur throughout the pre-Cambrian rocks of the New Jersey Highlands. Many of these ores contain a small amount of titanium, but in only a few instances does the percentage of titanium become as high as that usually contained in titaniferous magnetites. Furthermore, the occurrences with high titanium content are among the smaller deposits of the region, and will never be a factor in the utilization of such ores. The region was not visited for that reason; but because frequent mention is made in the literature of the titanium content of the New Jersey ores a brief account of the deposits will be given.

Practically all of the information available in regard to these ores has been included in the report on "Iron Mines and Mining in New Jersey," by W. S. Bayley,^a in which reference is made to the original sources.

FIELD RELATIONS OF REGION.

The pre-Cambrian rocks of New Jersey consist of gneisses, pegmatites, and a series of sedimentary rocks called the Franklin formation, of which the most important member is a white crystalline limestone.

These pre-Cambrian rocks form a series of ridges trending northeast, separated from one another by intervening valleys of Paleozoic rocks, and having a general southeast dip. Corresponding to the principal belts or ridges, the magnetites have been grouped into four belts, known from southeast to northwest as the Ramapo, the Passaic, the Musconetcong, and the Pequest. Magnetic iron ore occurs in all of the pre-Cambrian rocks, but the titaniferous ores are confined to the gneisses. The gneisses consist of alternations of potash rich, soda rich, and iron and magnesium rich rocks, called, respectively, the Byram gneiss, the Losee gneiss, and the Pochuck gneiss.

The origin of the gneisses is rather problematical, as they have been subjected to intense regional metamorphism. Wolff^b made a microscopic study of the gneisses at Hibernia and favors an origin by metamorphism of sediments. Westgate,^c who studied the rocks on Jenny Jump Mountain, is in doubt about the light-colored feldspathic gneisses, but favors an igneous origin for the dark hornblendic varieties. Bayley^d compares an analysis of a specimen of the hornblendic variety with an analysis of an Adirondack norite, and finds them chemically almost identical. Hence, though there is evidence pointing to the existence of metamorphosed gabbroitic rocks, the relation of the titaniferous ores to such rocks is not yet made clear. The titaniferous ores all occur within the areas mapped as acid gneisses, and not within the areas of the Pochuck gneiss. It seems, however, that intercalations of Pochuck gneiss too small to map occur in the acid gneisses, as the presence of such is mentioned at the Richard mine, though none is indicated on the map at that point. In other cases the character of the gneiss is not made clear.

Direct evidence that any of these ores are magmatic segregations in gabbros that have been subsequently metamorphosed is lacking. The very low titanium content of nearly all of the ores, with every gradation down to ores practically free from titanium, compared to the uniformly high titanium content of magmatic segregations of

^a Vol. 7 of the final-report series of the State geologist, 1910.

^b Wolff, J. E., Geological structure in vicinity of Hibernia, N. J., and its relation to the ore deposits: Ann. Rept. of State Geologist of New Jersey, 1893, pp. 359-369.

^c Westgate, L. G., The geology of the northern part of Jenny Jump Mountain, Warren County: Ann. Rept. of State Geologist of New Jersey, 1895, pp. 21-61.

^d Op. cit., p. 123.

titaniferous magnetites must be of some significance. It has long been believed, and the belief is founded on experience, that only magnetites segregated in gabbroitic rocks are titaniferous, or carry more than a very small amount of titanium; and when analyses of some of these New Jersey ores were found to run high in titanium it was only natural to try to connect those ores with rocks of that character. A notable exception to such a rule is the contact-metamorphic titaniferous magnetite on the Cebolla Creek in Gunnison County, Colo.^a It is true that the source of the ore on the Cebolla is a basic rock, nevertheless the method of origin was pneumatolytic, showing that considerable titanium can be carried away from the magma by pneumatolytic processes. A review of the theory of origin advanced by Bayley to account for the New Jersey magnetites is beyond the scope of this report, and for the present purpose it is characterized as of combined magmatic and pneumatolytic, or hydato-pneumatolytic, origin. The gneisses are regarded as of igneous origin. After their intrusion and partial cooling ferruginous portions of the same magma were intruded into them. These intrusions were subsequently enriched from the same source by iron-bearing solutions or vapors, which "made the ore lenses that now comprise the ore bodies." Bayley makes no exception of the titanium-bearing deposits, and it seems very probable that they belong to this class, and not to the true "titaniferous magnetites" discussed in this report.

It is quite probable that a few of the high titanium occurrences may be exceptions and do occur in metamorphosed gabbros. Thus the Church or Van Syckle mine in Hunterdon County shows in a series of analyses a TiO_2 content averaging about 12 per cent, which is well within the limits of such ores.

THE TITANIUM-BEARING ORES.

The table following gives the analyses of those magnetites that contain more than 1 per cent TiO_2 . They are derived from various sources, but are compiled in a series of tables in Bayley's report, the original source being given in each case.

^a See p. 138.

Results of analyses of New Jersey ores.

Name of mine.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	TiO ₂	P ₂ O ₅	S.	Cr ₂ O ₃	MnO	V ₂ O ₅	Insol.	Total.	Fe.
Baker.....	12.08	1.63	56.21	26.39	.88	1.08	.17			1.47	Trace.	0.00		0.00			61.94	
Bayard.....	7.14	1.23	90.89	25.94	1.40	1.31	.08			6.00	Trace.						49.50	
Beers.....	18.90	12.48	65.52		.86	4.45				7.83	0.09	.31		.00			54.46	
Bishop.....	16.15	3.34	68.48		1.94	4.87				1.98	.21	.39		.00			65.87	
Bloom.....	1.51	3.37	64.87	31.11	1.40	.51				4.77	Trace.	Trace.					37.5	
Cannon.....	6.37	1.59	57.46	27.23	1.01	2.93	.12			2.77	Trace.	.39		Trace.			63.53	
Charlotteburgh.....	9.80	9.48	73.15		.72	1.46				1.02	Trace.	(?)		Trace.			64.94	
Cramer I.....										9.95	.32	.00					62.23	
Cramer II.....										4.27	.90			Trace.			40.25	
Day.....	1.38	0.55	65.26	30.20	0.10	0.68	Trace.			5.08	.19	Trace.		.46			50.88	
DeKay.....	8.46	.77	50.13	27.81	1.88	1.68	0.22	0.36	0.12	4.68	.25	.41		.03	0.08		45.75	
Elizabeth.....									.28	1.09	.49	.01		.04	.11		69.24	
Hager.....										1.06	.98	.01	0.00	.00			61.02	
Do. c.....										1.40	.67	7.59		.00			56.13	
Do. d.....										7.13	.44						56.39	
Hagerty.....										4.27	.76	.05		.00			58.55	
Hann.....										1.07	.84	.09		.00			58.97	
Hibernia b.....	12.08	1.63	56.21	26.39	.88	1.08	.17		.17	1.21	.02	.03	Some.	.07	.21		59.93	
Do. c.....	7.14	1.23	90.89	25.94	1.40	1.31	.08	.13	.25	1.25	.53	.01	.00	.03	.15		62.85	
Holt Farm.....	18.90	12.48	65.52		.86	4.45				1.30	.06	1.23		.55			47.44	
Horton.....	16.15	3.34	68.48		1.94	4.87				1.09	.05	.01		.08	.13		49.58	
Hurd b.....	1.51	3.37	64.87	31.11	1.40	.51				1.05	.05	.01	.00	.00	.08		99.28	
Do. c.....	6.37	1.59	57.46	27.23	1.01	2.93	.12			1.70	.23	.05	.00	.03	.08		100.33	
Jackson.....	9.80	9.48	73.15		.72	1.46				4.40	.54	.06					100.14	
Kalant.....										1.42	.39	1.23					52.96	
Keeler.....										1.44	.39					12.00	52.34	
Leonard b.....	3.56	.44	61.47	55.24	1.68	1.66	.10			1.15	.54	.02	.00	.00	.08		98.84	
Do. c.....	7.62	.49	29.04	26.12	1.89	4.34	.27			1.05	.24	.02	.00	.04	.08		100.05	
Marsh.....										2.08	.38	.06		.00			99.04	
Martin.....										1.02	.38	.00					57.62	
Naughtlight c.....										9.40	.26	.41					49.25	
Old Iron.....										7.92	.16	.27				2.40	89.93	
Do. f.....										1.96	.00						64.77	
Richard b.....	1.31	.73	64.01	30.62	.43	.68	Trace.		.10	1.29	.56	.12	.00	.05	.10	4.10	100.30	
Richard c.....	3.77	.73	61.16	29.53	.63	1.23	.12	.14	.16	1.01	.00	.01	.00	.00	.10		98.38	
Do. c.....	8.48	.80	55.99	26.98	1.89	2.42	.33	.19	.15	1.01	1.54	.01	.00	.02	.08		99.95	
Shaffer.....										5.03	.21	.03		Trace.			60.34	
Stockholm.....										3.65	Trace.	.61		4.86			45.23	
Stony Brook.....										1.52	Trace.	.00		.00			67.10	
Van Syckle.....	5.40	9.29	69.34		3.55	.39				11.60	Trace.	1.21		.00			64.69	
																	50.20	

 a Three other analyses showed less than 1 per cent TiO₂.

b Selected sample. Tests for NiO, CoO, BaO, and SrO showed the absence of these constituents.

c Average sample. Tests for NiO, CoO, BaO, and SrO showed the absence of these constituents.

 d Other analyses show 4.15 and 5.73 per cent of TiO₂.

e Gray ore.

f Blue ore.

 g Another sample contained 0.30 per cent of TiO₂.

Bayley's report also includes 13 complete analyses of the ores in which V_2O_3 has been determined. These are of interest in comparison with the relation between the ratio of TiO_2 to V_2O_5 in certain Canadian ores and Adirondack ores as developed by Pope.^a Pope found that a number of nontitaniferous magnetites which he tested were free of vanadium, whereas the titaniferous magnetites always showed some vanadium. Moreover, the ratio of vanadic oxide (V_2O_5) to titanitic oxide (TiO_2) in the titaniferous magnetites from eastern Ontario and the Adirondacks was always in the neighborhood of 1 to 28. Consequently he suggested that in the titaniferous magnetites these two elements, vanadium and titanium, may be related to each other in a manner analogous to the relation of the oxides in definite ratios in the complex inorganic oxides studied by Gibbs, Marignac, and others.

The following table gives the percentages of TiO_2 and V_2O_3 determined in the New Jersey ores, and the ratio of TiO_2 to V_2O_5 calculated from them:

Vanadic oxide and titanitic oxide in the New Jersey ores.

Mine.	TiO_2 .	V_2O_3 .	$TiO_2 \div V_2O_5$.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Hibernia.....	0.54	0.14	3.2
Richard.....	1.29	.10	10.7
Do.....	.30	.11	2.3
Do.....	1.30	.095	11.3
Do.....	1.01	.08	10.4
Hibernia.....	1.21	.21	4.7
Do.....	1.25	.15	6.9
Leonard.....	1.15	.08	11.9
Do.....	1.05	.08	10.18
Elizabeth.....	1.09	.08	11.2
Do.....	1.06	.11	8.0
Hurd.....	1.05	.13	6.7
Do.....	.70	.08	7.2

It is apparent from the table that not only is the proportion of vanadic oxide compared to the titanitic oxide much greater in the New Jersey ores than in the ores studied by Pope, but also there is a wide variation from constancy in the ratio. The New Jersey ores can not be regarded as a fair test of the ratio, however, for, as already pointed out, they do not belong to the true "titaniferous magnetites." On the other hand, if they are thrown out of the class of titaniferous magnetites, the analyses would indicate that a vanadium content is not characteristic of the titaniferous ores alone.

NORTH CAROLINA.

Titaniferous magnetites occur at a number of localities in the Piedmont and Appalachian regions of North Carolina, but no deposits of great promise are known. The rocks of this western half of the

^a Pope, F. J., Investigation of magnetic iron ores from eastern Ontario: Trans. Am. Inst. Min. Eng., vol. 29, 1899, pp. 395-397.

State consist principally of a complex of gneisses, ranging from acidic or granitic gneisses to very basic rocks, as hornblende gneisses, granites, and other igneous rocks. The most recent and complete account of the titaniferous magnetites occurring in this region is contained in the bulletin on the iron ores of the State by Nitze.^a This report includes all information in previous reports of the State survey, and, except for data relative to the localities visited by the author of this report, it forms the basis of the following account.

As most of the localities cited in the North Carolina reports show no evidence of the existence of deposits of any importance, it was considered useless to attempt to visit all, and at the suggestion of Dr. J. H. Pratt, State geologist of North Carolina, the author visited what were considered the two most promising areas, the belt extending across Rockingham, Guilford, and Davidson Counties, just west of Greensboro, and the area to the north of Lenoir, in Caldwell County.

The general distribution and character of the ores is very briefly indicated; a more detailed description is given only of the two areas visited by the writer.

DISTRIBUTION AND CHARACTER OF THE ORES.

References to the character of the immediate country rock of the ores are very meager and of a most general nature. All that can be gotten from the literature is that it is in most cases a schistose femic rock. No information as to what the original rock might have been is given. Little can be said, therefore, in regard to the geology of the ores.

Our knowledge of the character and extent of the ores is more complete, as a large number of analyses have been made, and some data are given indicating the size of the ore bodies. The table following gives the available analyses, arranged alphabetically by counties. It is the same as that given by Nitze,^b with five analyses added in Guilford County taken from Lesley.^c

^a Nitze, H. B. C., A preliminary report on the iron ores of North Carolina: North Carolina Geol. Survey Bull. 1, 1893.

^b Op. cit., pp. 229-231.

^c Lesley, J. P., Notes on the titaniferous iron belt near Greensboro, North Carolina: Proc. Am. Phil. Soc., vol. 12, 1871, pp. 154-156.

Results of analyses of North Carolina ores.

Source of ore.	SiO ₂	Fe.	Mn.	S.	P.	TiO ₂	Cr ₂ O ₃	Al ₂ O ₃	CaCO ₃	MgCO ₃	CaO.	MgO.
ALLEGHANY COUNTY.												
1. Fielden Carrieco, Old Forge workings.....	Per cent. 6.20	Per cent. 54.72	Per cent. 0.038	Per cent. 0.047	Per cent. 4.85							
ASHE COUNTY.												
2. Cicero Pennington, Wallens Creek.....	4.75	52.23	.112	.021	8.91							
3. Cicero Pennington, Wallens Creek.....	4.72	52.41	.077	.004	5.38							
4. Cicero Pennington, Wallens Creek.....	5.07	52.45		.022	9.11		1.19					
5. Baugnass opening, near Little Helton Creek.....	6.85	57.66	.061	.008	4.69		.505					
6. Baugnass opening, near Little Helton Creek.....	7.91	53.55	.078	.022	4.92		.63					
7. G. C. McArthur, Little Helton Creek.....	9.90	46.81	.137	.025	6.63							
8. G. C. McArthur, Little Helton Creek.....	10.92	40.71	.065	.012	8.54							
9. G. C. McArthur, Shipp's Branch opening.....	5.57	51.55		.018	9.17							
10. William Young, Little Helton Creek.....	5.12	50.77	.04	.005	4.95							
11. William Young, Little Helton Creek.....	4.35	52.85		.013	8.80							
CALDWELL COUNTY.												
12. J. K. Farthing, Warrior Creek.....	6.50	31.92	0.39	.025	2.40				7.48	15.64		
13. Joshua Curtis, Yadkin River (average).....	6.63	36.91	1.19	.021	14.90				7.37	16.08		
14. Joshua Curtis, Yadkin River (selected).....	7.55	28.24	.013	.140	41.21							
15. Joshua Curtis, Yadkin River.....		37.10		Trace.	36.40							
16. Joshua Curtis, Yadkin River.....		25.76		.076	38.81							
CATAWBA COUNTY.												
17. Forney ore bank, near Maiden Station.....	1.41	67.92		.07	1.60							
DAVIDSON COUNTY.												
18. K. R. Swain, massive ore.....	.76	57.68			13.52		.46	1.68				
19. K. R. Swain, micaceous ore.....	5.68	52.68			11.67		.48	5.68				
DAVIE COUNTY.												
20. Kelley-Leffer place, 5 miles south of Mocksville.....	.778	60.00		.008	10.32							
21. Allen place, 7 miles northeast of Mocksville.....	5.50	52.80	.033	.02	8.00							
GUILFORD COUNTY.												
22. Elisha Charles.....	.40	59.03			11.95		1.07	1.06				
23. Widow Cook.....	1.84	56.21			13.28		.65	2.30				
24. John Clark.....	1.30	56.41			12.35		1.10	2.54				
25. Sargeant shaft.....	1.31	55.66			13.60		.72	4.26				
26. Sargeant shaft.....		53.20		.005	Present.							

27. Sargeant shaft.....	12.86	53.27				13.58						
28. Mrs. McCuiston, soft micaceous.....		43.47				16.06						
29. Mrs. McCuiston, soft micaceous.....	12.75	41.95				16.39						
30. Mrs. McCuiston, magnelic part of above.....	1.30	67.60				1.27						
31. Mrs. McCuiston, nonmagnetic part of above.....	26.80	21.63				16.20						
32. Mrs. McCuiston, massive ore.....		33.97				2.63						
33. W. A. Lewis.....	50	57.32				12.27						
34. Belt west of Greensboro a.....	75	57.77	.32			12.08						
35. Belt west of Greensboro.....	1.80	59.95	.32			8.72						
36. Belt west of Greensboro.....	1.04	58.52				12.32						
37. Belt west of Greensboro.....	1.50	60.41	.08			8.65						
38. Belt west of Greensboro.....	.52	57.30	.48			13.74						
LINCOLN COUNTY.												
39. Lawson Bess, Indian Creek.....	11.37	56.95				.029						
MACON COUNTY.												
40. Felix Kilpatrick, 5 miles east of Franklin.....	.77	54.24				.013						
41. Alex. Waldrop, 6 miles west of Franklin.....	11.91	20.64	.69			.016						
MADISON COUNTY.												
42. Road, midway between Asheville and Burnsville.....	.83	36.26	.63			.09						
43. John Brigman, Paint Fork.....						Trace.						
44. Swan Woody, Spring Creek.....	2.37	62.16				.014						
MITCHELL COUNTY.												
45. Avery land, Roaring Creek, Yellow Mountain.....	1.46	65.32				.025						
46. Avery land, Roaring Creek, Yellow Mountain.....	.54	66.95				None.						
47. Parker place, 2 miles west of Burnsville.....	1.22	57.98				.015						
48. Joel Gouge, mouth of Little Rock Creek.....	1.13	64.56				.027						
49. Above Jenkins mine, Greasy Creek.....	6.58	54.43				.023						
ROCKINGHAM COUNTY.												
50. Levi Shaw.....	1.80	54.17	.96									
51. P. Hopkins.....	1.74	53.61	.82									
52. Granular reddish ore.....	1.38	30.57	.63									
53. Granular grayish ore.....	.58	33.52	.80									
54. Dannemora mine.....	4.71	48.41				.059						
55. Dannemora mine, fine ore.....		49.41	Trace.			.023						
YANCEY COUNTY.												
56. Mine Fork, 6 miles north of Burnsville.....	9.25	39.42				.12						
57. Jerry Ferguson, 9 miles west of Burnsville.....	23.38	39.00				.011						

* Ore represented by this analysis had a trace of V_2O_5 .

These analyses show a considerable range in TiO_2 content; whereas a number carry only a small percentage of TiO_2 , others have such a high percentage that the ore must consist almost entirely of ilmenite. The phosphorus ratio in nearly all of the ores is below the Bessemer limit, and sulphur is low. The percentage of iron is also high in most of the analyses. Except for their titanium content, most of the ores would be classed as medium to high grade.

ALLEGHANY COUNTY.

A zone of hornblende schists, in many places altered to steatite or soapstone, and carrying crystalline grains of magnetite, usually titaniferous, extends across Alleghany County parallel to the Little River and usually on the south side of it. Locally the magnetite becomes more abundant in the schists and may be sufficiently concentrated to form small lenses of ore. On the farm of Fielden Carrico, near the State line, several such ore bodies were opened up about 30 years ago to supply a near-by forge in Virginia (see analysis 1). These openings have long since been abandoned and caved in.

ASHE COUNTY.

A belt of titaniferous magnetite extends in a northeasterly direction from Helton Creek near Sturgill to Little Helton Creek, a distance of $2\frac{1}{2}$ miles. The analyses of the ores in this belt (analyses 2 to 10) show a moderate titanium content.

At the northeast end of the belt is a series of outcrops, one of which shows an ore bed at least 25 feet wide. It is a coarse granular magnetite practically free from gangue. The country rock is in part a prophyllite schist and in part a hornblende rock altering to asbestos. South of these outcrops is another showing 5 feet of ore with a gangue of epidote, feldspar, and quartz. At the southwest end of the belt are several more outcrops, in which the width of the ore ranges from 8 to 15 feet. The ore is a fine-grained magnetite with a gangue of hornblende and epidote.

CALDWELL COUNTY.

Two localities in this county were visited by the writer, but neither showed either large or promising deposits.

RICHLANDS COVE DEPOSIT.

Sixteen miles north of Lenoir in what is known as the Richlands cove is a body of titaniferous iron ore on the east bank of the Yadkin River. A small opening has been made adjacent to the river bank exposing a face about 20 feet high and 40 feet wide. This titaniferous mass occurs within a country rock consisting of sericitic schist. It consists of small particles of ore in a matrix chiefly made

up of fibrous and scaly aggregates of chlorite, serpentine, and talc. The individual ore particles average less than one-half mm. in diameter, and rarely exceed 1 mm. They are very slightly magnetic to nonmagnetic. Two polished sections of the ore etched with hydrochloric acid retained their luster and showed no evidence of the intergrowths of ilmenite and magnetite. These facts, together with the high titanium content shown in the analyses in the table (analyses 13 to 16), indicate that the ore particles consist chiefly of ilmenite. This is further borne out by the fact that the sands along the river close to the deposits contain only nonmagnetic ore particles.

Just north of the opening on the river bank is a small side valley in which a rock of identical character outcrops. This outcrop is about 300 feet from the river on the north side of the valley.

Neither of these deposits shows extensive outcrops, and they seem to be only small intercalations in the more acidic country rock. They undoubtedly represent small basic intrusions that have undergone metamorphism with the rest of the region.

The titanium content is so high that the deposits can not be regarded as iron ores. As sources of titanium, their inaccessible location and seeming small size are great drawbacks. At present they possess no economic value.

FARTHING DEPOSIT.

On the north side of Warrior Creek, $5\frac{1}{2}$ miles north of Lenoir, there are outcrops of an ore-bearing rock. The rock consists principally of a green hornblende schist carrying considerable ore disseminated in minute grains and in stringers of nearly pure ore. It occurs as an intercalation in more acidic schistose rocks. Similar rock can be traced for some distance to the southwest by means of surface fragments, but no openings have been made on this occurrence.

Locally this hornblende rock contains richer portions of fine-grained ore. A thin section of such a piece consisted principally of the ore minerals and spinel. Less abundant were augite and hornblende. The ore grains are less than 0.5 mm. in diameter, and do not constitute more than one-third of the mass. On etching polished surfaces of these ores, the small magnetite grains are dissolved out without showing any ilmenite intergrowths, and the polished surfaces of the ilmenite remain unattacked. Further evidence that the small pits on the polished surface were occupied by magnetite is the fact that a considerable part of the powdered ore is magnetic. Analysis 12 shows the composition of the ore.

Adequate exposures to enable one to judge accurately the extent of the occurrence are lacking. The richer parts of the rock are so lean, however, as to preclude any possibility of working the deposit.

CATAWBA COUNTY.

A belt of titaniferous ore extends across parts of Catawba and Lincoln Counties, from a point southwest of Newton to about 9 miles west of Lincolnton. At the northeast end is the Forney mine, which formerly supplied several forges in the neighborhood. The ore is a coarse granular magnetite, usually free from gangue, and occurs in irregular pockets a few inches to 3 or 4 feet in thickness. The country rock is called syenite in the North Carolina report. An analysis of the ore (analysis 17) shows a low titanium content. Float ore found in this belt at the southwest end also shows (analysis 39) only a small percentage of titanium.

DAVIDSON COUNTY.

See Guilford County.

DAVIE COUNTY.

Titaniferous ores are described at two points in Davie County near Mocksville.

About 5 miles south of Mocksville, near the mouth of Bear Creek, is a fair showing of float ore for a distance of 600 feet on the old Maxwell place. Float ore can be traced at intervals for $1\frac{1}{2}$ miles to the southwest to the South Yadkin River. The country rock is described as "hornblende and syenite, with occasional dissemination of magnetite granules." The ore is a medium grain magnetite with little gangue (analysis 20).

Similar ore occurs 7 miles northeast of Mocksville and 1 mile east of Kernatzer station. Several pits and a shaft were put down here during the Civil War. The ore was worked in a forge 4 miles distant on Dutchmen's Creek. Float ore can be traced faintly 200 to 300 yards northeast and southwest of the old shaft (analysis 21).

GUILFORD COUNTY.

A belt of titaniferous magnetite extends across Guilford County in a northeasterly direction, and passes beyond the boundaries of Guilford County into Rockingham County on the northeast and into Davidson County on the southwest. It lies to the north and west of Greensboro. It consists of two parallel subordinate belts known, respectively, as the Tuscarora belt and the Shaw belt, the total length of which is 30 miles. The longer and more persistent is the Tuscarora belt. The Shaw belt lies several miles northwest of it.

The area is one of prevailing granites and gneisses within which are smaller bodies of gabbro. Though evidence of the presence of the gabbro is obtained repeatedly along the belt by outcrops and surface fragments, it seems that the belt is not one elongated mass of gabbro, but consists of a number of smaller masses having a linear distribution along the belt. The ore bodies are segregations within

these small gabbro masses and do not constitute a continuous body extending the entire length of the belt.

Surface outcrops of the ore bodies are lacking, and as the old workings have all caved in the character of the ore can be judged only from the surface fragments. A detailed examination of the belt was made by Lesley^a for a Philadelphia mining company, and trenching was done at a number of points to expose the ore. Dr. Lesley consequently had unusual opportunities for observing the ore bodies, and his account of them is the most valuable we have. Shortly after this the belt was visited by Prof. W. C. Kerr and Dr. F. A. Genth, and described in a report of the North Carolina geological survey.^b The descriptive part is taken mainly from Lesley's report, but 16 additional analyses made by Genth are given. This same report was reprinted with slight alterations in 1883^c and again in 1893.^d A brief sketch is also given in the Tenth Census reports.^e

It is not surprising that Dr. Lesley at that early date misinterpreted the genesis of the ores. He regarded them as bedded deposits of sedimentary origin, and consequently the conclusions he drew as to the geology and structure of the deposits are erroneous. These are of historical interest only and will not be repeated here. The records of his observations, however, supply facts no longer accessible on account of the filling of the old workings and trenches. The ore bodies consist of strings of lens-shaped masses, continually enlarging and contracting in thickness from a few inches to 6 and 8 feet. "The principal beds may be safely estimated at an average of 4 feet, and in the best mining localities the average yield of a long gangway may reach 5 feet." The occurrence of the ore body in a series of disconnected lenses is consequently verified by the observation of Prof. Lesley.

TUSCARORA MINE.

This mine was worked in the seventies by a Philadelphia mining company. Forges were erected on a small stream a half mile north-east of the principal shaft, and considerable iron is said to have been made. It seems that the titaniferous ores could readily be smelted in the old Catalan forges and yielded a superior grade of iron. The Tuscarora mine consisted of several shafts extending about a mile along the ore belt. The principal shaft, the Sargeant, was situated a mile and a half north of Friendship. It reached a depth of 109 feet, and a tunnel run in from this depth is said to have cut a bed 12 feet wide.

^a Lesley, J. P., Note on the titaniferous iron-ore belt near Greensboro, N. C.: *Proc. Am. Phil. Soc.*, vol. 12, 1871, pp. 139-156.

^b Report of the Geological Survey of North Carolina, vol. 1, 1875, pp. 236-250.

^c Kerr, W. C., and Hanna, G. B., Ores of North Carolina: *Geol. Survey of North Carolina*, 1888, pp. 143-154.

^d Nitze, H. B. C., A preliminary report on the iron ores of North Carolina: *North Carolina Geol. Survey Bull.* 1, 1893, pp. 60-68.

^e Tenth Census, vol. 15, 1886, pp. 308-311.

Outcrops of granitic gneisses occur in the vicinity of the mine, but the immediate country rock is a gabbro. It is an olivine gabbro with diabasic texture, in which the feldspar laths reach a length of $2\frac{1}{2}$ mm., and the pyroxene and olivine grains have a diameter of 1 to $1\frac{1}{2}$ mm.

No ore in place is now exposed, but judging from fragments lying about on the surface it is a medium to coarse grained ore of good grade, in which the principal gangue consists of tufts and seams of chlorite and small quantities of material so decomposed as to make it undeterminable. Analyses 25 to 27 give the composition of the ore.

METALLOGRAPHIC DESCRIPTION OF ORE.

Polished sections of this ore show very striking features. Gangue minerals constitute only a small part of the surface. Ilmenite grains make up one-fifth to two-fifths of the surface; and they range in size from 2 mm. to 0.2 mm., though very few fall below 0.5 mm. in diameter. The most striking feature of the ore is the ilmenite intergrowths in the magnetite, which attain a coarseness not approached in any of the other ores that have been studied. Indeed, so coarse are they as to be easily discernible with the naked eye. An etched specimen of the ore is shown in Plate II, *C*, in which the relations of the ilmenite and the magnetite grains and the heavy ilmenite laths in the magnetite are apparent. The individual ilmenite plates have an average length of 2 mm., but some attain a length of as much as 4 mm. The space between the parallel plates varies from 0.2 to 0.5 mm., and the plates themselves may be as thick as 0.1 mm. Another characteristic feature is protuberances or local thickenings of the plates. This most frequently takes place at one end, the other end thinning out, giving an elongated, wedge-shaped appearance. These plates are plainly visible on cleavage faces of the magnetites on the unpolished surfaces of pieces that have been etched, and are frequently coarse enough to peel off with the edge of a knife blade. The structure is shown in Plate VII, *A*.

POSSIBILITIES OF UTILIZING ORE.

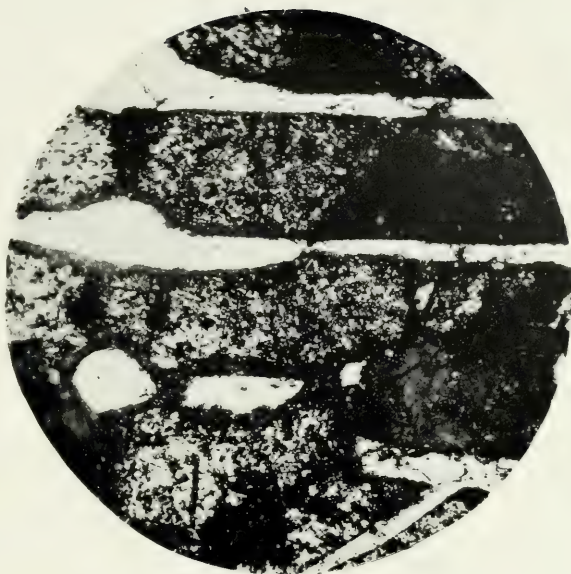
The most satisfactory results of magnetic separation were obtained from this ore, as shown below:

Results of magnetic separation of Tuscarora ore.

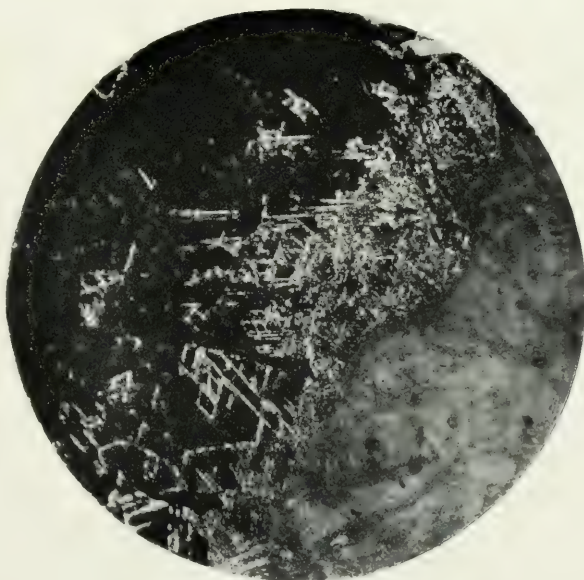
	Un-screened ore.	Ore through 50-mesh, over 100-mesh. ^a		Ore through screen finer than 100-mesh. ^b
		Magnetic.	Nonmagnetic.	Magnetic.
	Per cent.	Per cent.	Per cent.	Per cent.
Quantity.....				
Fe.....	58.07	71.5	28.5	70.1
TiO ₂	12.82	4.25	34.32	3.64

^a 44.6 per cent.

^b 55.4 per cent.



A. TUSCARORA MINE, N. C., ORE. ($\times 60$.)



B. IRON LAKE, MINN., ORE. ($\times 60$.)



These results show that little is to be gained by grinding finer than 50-mesh; that is, notwithstanding the coarseness of the ilmenite intergrowths they are still too fine to be separated by grinding to 100-mesh. This of course is obvious from a comparison of the dimensions of the intergrowths given above and the size of the openings of the 100-mesh screen. If all the TiO_2 in the tailings is assigned to the ilmenite, they contain about 75 per cent ilmenite, with a residue of 6.38 per cent Fe. Some of this iron occurs in the gangue minerals present, so that very little magnetite is lost by adhering to the ilmenite or gangue. Although the titanium content of the concentrate is still higher than is acceptable in present blast-furnace practice, the concentrate is so high grade that it would make an acceptable ore to mix with titanium-free ore.

Kerr ^a gives the results of a magnetic-separation test made with a common magnet on ore obtained from this same belt several miles northeast of the Tuscarora mine. They are even more favorable than those presented above.

Results of magnetic-separation test of Tuscarora ore.

Constituent.	Natural ore.	Magnetic.	Nonmagnetic.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	41.95	67.60	21.63
TiO ₂	15.35	1.27	16.20
SiO ₂	12.75	1.30	26.80

TRUEBLOOD PLANTATION ORE.

About 2 miles northeast of the Tuscarora mine, on the south side of Brushy Creek, a little work has been done. The ore here also occurs in association with a gabbro. The gabbro is strongly uraltized and the feldspar sufficiently altered to make the twinning obscure in places. Diabasic texture is far less prominent than in the rock of the Tuscarora mine, and often lacking entirely. The average size of the grains is about 2 mm.

The ore is not quite as coarse as the Tuscarora mine ore, and etched sections do not show the intergrowths as abundantly. Otherwise the ore at the two localities is very similar in appearance.

APPLE PLANTATION ORE.

Some pits were put down on the Apple plantation just over the line in Rockingham County, southeast of the Haw River, but they are all filled now. Fragments of ore found on the surface are similar to the ore found on the Trueblood plantation. Of special interest to this locality are fragments of pink and gray emery. The occurrence

^a Report of the Geological Survey of North Carolina, vol. 1, 1875, p. 245.

of emery in this belt is first mentioned in Kerr's report,^a in which he gives two analyses made by Genth. One analysis is of a reddish granular ore (analysis 52), which he describes as follows: "It has much the appearance of a granular reddish-brown garnet, for which it has been mistaken, until the analysis proved it to be not a silicate mixed with granular magnetite, but corundum." The other is of a granular grayish ore (analysis 53) described as follows: "This is of a similar quality and is found at the same locality; the minute grains of corundum have a yellowish or brownish-white color, and show in many places cleavage fractures, which give it the appearance of a felspathic mineral." No mention is made of the locality where these specimens were found. Pratt and Lewis^b state that the exact location is not now known, and give the McCarviston or McCuiston place, 7 miles northeast of Friendship, in Guilford County, as the probable location. The specimens found on the old Apple plantation fit the description given by Kerr exactly, and as no such material was found anywhere else in the belt, it seems probable that this is the locality from which Kerr's specimens were obtained. The rock was not found in place and no conclusions could be drawn as to the occurrence and size of the deposit.

DANNEMORA MINE.

Some work was done on the Shaw belt, 3 miles west of Summerfield, but the only extensive workings were those on the north side of the Haw River, close to the line between Guilford and Rockingham Counties. Ore was worked from pits in Revolutionary times, and hauled to Troublesome Forge, 5 miles to the north. Subsequently a Philadelphia mining company worked the Dannemora mine on this property. The following description of the mine, given by Bailey Willis in the Tenth Census report,^c is quoted because it gives the size of one of the ore lenses:

The first work was done in incline No. 1. According to the statement of the superintendent the ore gave out 10 feet from the surface but was found again 20 feet farther down; it widened to 12 feet, which is the thickness 90 feet from the surface in the incline, 70 feet vertically. At this depth a drift has been driven along the vein and stoping has been begun. A small winze has been sunk 20 feet farther on the incline, and the ore is said to narrow to 1 foot in thickness. Before the horizontal drift reached the second incline the ore was pinched out by the granite walls.

As the ore body thus opened gives out just beyond incline No. 1, its dimensions are pretty well ascertained. It is approximately 125 feet long, 80 feet in incline width, and 12 feet thick. The drift has been extended to another lens of the same thickness, northeast of it, and the surface outcrops and trenches indicate the existence of others to the southwest. The ore is accompanied by chlorite and mica, which are sufficiently

^a Report of the Geological Survey of North Carolina, vol. 1, 1875, p. 246.

^b Pratt, J. H., and Lewis, J. V., Corundum and the peridotites of western North Carolina: North Carolina Geol. Survey, vol. 1, 1905, pp. 263-264.

^c Tenth Census, vol. 15, 1886, p. 308.

decomposed, even at the depth of the tunnel, to be readily dug with a pick. The ore is separated on the surface, by screening, into lump and fine ore, the former being shipped for fettling, the latter for blast-furnace use.

The ore lying about the old workings is somewhat leaner than the Tuscarora-mine ore. It consists of a similar granular aggregate of ilmenite and magnetite with the gangue minerals, but the individual grains seldom exceed 1 mm. in diameter, and most of them are about 0.5 mm. Intergrowths of ilmenite in the magnetite grains are almost lacking.

SUMMARY.

The titanium content of these ores is about the normal one for titaniferous magnetites. Of the large number of available analyses the average TiO_2 content is about 13 per cent. The ilmenite and the magnetite occur as granular aggregates in the ores in such a manner that most of the titanium can be eliminated with little loss of magnetite. The resulting concentrate runs high in iron and is low enough in titanium to make possible the utilization of these ores in normal blast-furnace practice by mixing them with titanium-free ores. On the other hand, little is known in regard to their geologic occurrence and size on account of lack of exposures. Such conclusions as can be drawn from old data and the nature of the deposits are not very favorable to them. The ore bodies seem to be rather small and irregular in distribution, so that mining operations would be attended by considerable uncertainty. On the whole, therefore, the belt is not very promising as a source of iron ore.

LINCOLN COUNTY.

See Catawba County.

MACON COUNTY.

There are a number of occurrences of titaniferous magnetite in Macon County east and south of Franklin, but none has been explored more than superficially.

Five miles east of Franklin and one-eighth of a mile north of Culasagee Creek there is a heavy surface float of massive lustrous magnetite high in titanium (analysis 40). The gangue is quartz and chlorite; the ore is traceable for several hundred yards along the summit of a hill in a northeasterly direction parallel to the strike of the decomposed mica schists near the foot of the hill.

An analysis has also been made of the ore on land 4 miles southwest of Franklin and 2 miles above the mouth of Cartoogajay Creek (analysis 41). The ore is very fine grained, in a chloritic gangue, and in places slightly garnetiferous. The extent of the ore body is not apparent.

MADISON COUNTY.

No important bodies of titaniferous ore are known in Madison County, though there are several occurrences of the ore.

In the eastern part of the county, a half mile above the mouth of Paint Fork, small pieces of float ore high in titanium are found (analysis 43). The occurrence of a highly titaniferous ore is also noted near the road midway between Asheville and Burnsville (analysis 42).

An occurrence showing only a moderate amount of titanium is that a half mile east of the Haywood County line near the headwaters of Spring Creek (analysis 44). It has a thickness of 5 to 6 feet near the surface and appears to widen in depth.

MITCHELL COUNTY.

Titaniferous ores occur in Mitchell County in the Roan Mountain belt, the Pumpkin Patch Mountain belt, and on Iron Mountain.

Titaniferous ore occurs on one of the spurs of Iron Mountain $2\frac{1}{2}$ miles above the mouth of Greasy Creek, near the Jenkins ore bank (analysis 49). The ore body consists of a compact lustrous ore free from gangue, and attains a width of $5\frac{1}{2}$ feet. The wall rock is hornblende gneiss and pegmatite.

The Roan Mountain titaniferous belt lies several miles south of the Cranberry belt to which it is parallel. Its eastern extremity is near the mouth of Roaring Creek on one of the southern spurs of Big Yellow Mountain. It crosses the State line on the summit of Grassy Bald Ridge, then, after traversing the eastern edge of Tennessee for about 4 miles, bends around to the southwest and reenters North Carolina near the headwaters of Big Rock Creek; thence it continues to the mouth of Big Rock Creek to the Yancey County line at Toe River. No ore bodies of any size have been found along this belt. At the eastern end some prospecting has been done, including the drilling of three diamond-drill holes. The results were discouraging, as the ores occur in lenses of 2 inches to 2 feet in width. The titanium content is only moderate in amount (analyses 45 and 46). The ore is compact, lustrous, and free from gangue, and occurs in a country rock of very coarse-grained pegmatite, hornblende schist, epidote, and garnet rock.

At the southwest end of the belt on the north side of Little Rock Creek a small pit exposes a bed 3 feet wide, which at a depth of 4 feet is cut out by a diabase dike (analysis 48).

The Pumpkin Patch Mountain titaniferous magnetite belt lies to the northwest of Bakersville and has an extent of 5 to 6 miles. Some pits have been put down on the Parker place near the head of Wadkins Branch, 5 miles northwest of Bakersville, and loose blocks of

ore encountered (analysis 47); the pits did not go deep enough to get the ore in place.

All of these Mitchell County ores show approximately the same titanium content.

ROCKINGHAM COUNTY.

See Guilford County.

YANCEY COUNTY.

The occurrences of iron ore in Yancey County are isolated and sporadic, and no notable occurrences of titaniferous ore have been disclosed.

In the extreme western part of the county near the head of Possum Trot Creek, 9 miles west of Burnsville, is found float ore that shows a small amount of titanium (analysis 57). It is possible that this occurrence belongs to the Roan Mountain titaniferous belt of Mitchell County.

Another deposit occurs 6 miles north of Burnsville, on the south side of Mine Fork, a half mile above its mouth (see analysis 56). Two small openings were made 75 feet apart on the strike of the ore (N. 25° E.) and show a vertical bed of ore 6 to 10 feet across. The ore is in a gangue of chlorite, small particles of quartz and feldspar, and a peculiar brown mineral of high luster which may be rutile or brookite. A quarter mile southwest of these openings is much surface float of this heavy brown mineral nearly free from magnetite. If this mineral is really rutile or brookite, considerable titanium could easily be eliminated by magnetic concentration.

MINNESOTA.

Titaniferous magnetite occurs within an extensive area of gabbro in northeastern Minnesota known as the Duluth laccolith. This forms part of the pre-Cambrian region of Lake Superior, and the geology and petrography of it have been referred to repeatedly by the geologists who have worked in this field. The geology of the ore bodies is so simple and that of the entire area so complicated that it would be a needless use of space in this report to attempt to give a résumé of the geological literature embracing this area. A bibliography of the literature is given in Monograph 52 of the United States Geological Survey.^a

Describing the areal distribution of the great gabbro mass Elftman^b says:

The gabbro forms the outer or northern member of the Keeweenawan series. The general shape of the area is crescentic with the concave side toward Lake Superior.

^a Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey, 1911, pp. 78-80.

^b Elftman, A. H., The geology of the Keeweenawan area in northeastern Minnesota: Am. Geol., vol. 22, 1898, p. 132.

The horns of the crescent are located, the one near Duluth and the other near East Greenwood Lake, T. 64 N., R. 2 E. The chord connecting them is 125 miles long and runs northeast and southwest. The maximum width of the area is 25 miles. The surface area is about 2,400 square miles in extent.

PETROGRAPHY OF THE GABBRO.

Detailed petrographic descriptions of the gabbro are given in several of the articles cited in the bibliography mentioned above. For the purposes of this description the concise statement made by Van Hise and Leith ^a will suffice.

It is, for the most part, normal gabbro, but it has many facies. Mineralogically it varies from a very magnetitic gabbro through olivine gabbro in which the feldspar is subordinate and ordinary olivine gabbro to olivine-free gabbro, or ordinary gabbro, and finally to a rock in which feldspar is the dominant mineral, the rock being a labradorite or an anorthosite. * * *

Structurally the gabbro is ordinarily massive. However, at many places, especially near its borders, it has a sheeted structure. Some of the sheets are very thin and strongly resemble bedded rocks. * * * In addition to this sheeted structure there is a banded structure, due to the parallel arrangement of the mineral constituents.

Texturally the gabbro varies from a rock of very coarse grain to one that is almost aphanitic. All varieties, coarse and fine, are granulitic.

AGE AND RELATIONS OF GABBRO TO OTHER FORMATIONS.

The age and relation of the gabbro to the formations with which it comes in contact have been variously interpreted by different workers. The interpretation of Van Hise and Leith is most in accord with the facts now available and is the one here given.^b

The structural relations of the Duluth gabbro are very interesting. On the north, in passing from St. Louis River to Grand Portage, the gabbro is in contact for a long way with the upper Huronian, then for many miles with the several members of the lower Huronian and the Archean, and finally for many miles again with the upper Huronian. It thus cuts diagonally across the upper Huronian in its northern and southern parts and in passing toward the center of the area goes through the lower Huronian and deep into the Archean.

Evidence of its intrusive character is afforded by its coarse crystallization; by the presence of numerous subordinate bosses and dikes, offshoots of the gabbro mass, in the Huronian series; by the inclusion of isolated masses of upper Huronian near its margin and the profound metamorphic effects of the gabbro, the rocks being changed to schists or gneisses or even completely granular crystalline rocks for distances up to half a mile or a mile from the main gabbro mass, an effect not to be expected from a rapidly cooling extrusive; and finally by the higher density of the gabbro than of the intruded rocks.

The relations of the gabbros to the lavas of the coast have not been satisfactorily determined. Their contact is mainly in the plateau of the interior, is very poorly exposed, and has not been sufficiently studied. However, it is believed that when these relations are worked out it will be found that the gabbro is intrusive and has produced profound metamorphic effects.

^a Op. cit., p. 372.

^b Op. cit., pp. 372-373.

If this inferred intrusive relation is confirmed, the Duluth gabbro is a great laccolith, which has as a basement the Huronian and Archean, and as a roof the Keeweenawan lava flows. The relations of the Duluth gabbro to the Puckwunge conglomerate at the base of the Keeweenawan and to the earlier Keeweenawan lavas have not been established. Until this is done it is impossible to gain any conception as to how far Keeweenawan time had advanced before the appearance of the gabbro. If the Duluth gabbro is interpreted as a laccolith it surpasses in magnitude any other yet described. With a maximum diameter of 100 miles, if its thickness has approximately the ratio shown in the typical laccoliths of the Henry Mountains,^a the thickness would be 75,000 feet. If an average dip of 10° for 50 miles on the north shore is assumed the thickness would figure 45,000 feet.

The intrusion of so vast a mass of material must have required a long time. The parts earlier intruded were doubtless solidified long before magma ceased to enter. Thus offshoots of these later parts would be found as dikes in the earlier solidified parts. There would be great variation in its coarseness of crystallization. Ample time would be afforded for differentiation by fractional crystallization, separation by gravity, and other processes, and thus is explained the structural complexity of the gabbro and its great variation in mineral and chemical character.

TITANIFEROUS MAGNETITES IN THE DULUTH GABBRO.

The occurrence of titaniferous magnetite in the gabbro of north-eastern Minnesota has been known for nearly 40 years, and numerous references to the deposits are found in the literature. The data supplied, however, are of such an indefinite and general character that little conception can be gained of the actual economic importance of the ores. The quotations and abstracts in the following paragraphs include practically all the information that has been published in regard to them. The list is, by no means, however, a complete record of references to the deposits.

In the report of the State chemist, S. F. Peckham, for the year 1876, is the following statement:^b

A sample of iron ore, supposed to contain tin, from the neighborhood of Duluth, was sent to Prof. E. W. Morley, of Hudson, Ohio, a gentleman of large experience on iron assays. He reported two assays as yielding iron, 16.19 per cent and 16.17 per cent. "Tin not present in any appreciable quantity. The ore appeared to contain quite a notable quantity of titanium. * * *." Another sample of iron ore from near Duluth sent to Prof. Morley was reported as "an iron-magnesium-sodium silicate; with not enough iron to make it of value as an iron ore."

Referring to this statement in 1887, Winchell says:^c

At that time some local interest was awakened over the supposed existence of valuable ore deposits within the corporate limits of the city of Duluth. It is sufficient to say that the excitement soon subsided when it became known that the ore was likely to run low in iron, and that the amount that was known to exist was quite limited. Besides these facts, the presence of a considerable percentage of titanium would have operated disastrously upon the enterprise had the discovery been pushed far enough to have been worthy of the name.

^a See Gilbert, G. K., *The geology of the Henry Mountains*: U. S. Geog. and Geol. Survey, Rocky Mtn. Region, 1880, p. 55.

^b Fifth Annual Report of the Geological and Natural History Survey of Minnesota, 1876, p. 63.

^c Winchell, N. H., *Fifteenth Annual Report of the Geological and Natural History Survey of Minnesota*, 1886, p. 212.

Winchell,^a referring to ore which he found on the north shore of Iron Lake, says: "This iron ore constitutes what is locally known as the 'Mayhew Iron Range,' and is found in a belt about a mile wide on both sides of Iron Lake, and on the south side of Portage Lake, and between Portage and Poplar Lakes. An analysis reported by Mr. Hause, performed by R. S. Robertson, of Pittsburgh, Pa., gave the following result: Silica, 2.02; alumina, 2.68; titanium, 12.09; sesqui-chromium, 2.40; mag. ox. iron, 80.78; lime, trace; phos. acid, 0.03." A careful study of this location warranted among others the following statements:^b

First. The ore is in the igneous rock.

Second. It varies in quality very much, even passing into rock that can not be styled iron ore.

Tenth. The iron in considerable but unknown quantity is of fine quality, being seen in other places besides this described.

From several assays Mr. Hoare states that he ascertained the iron and titanium together in the ore from Iron Lake to be pretty nearly uniform throughout, but that the titanium varied from 6 to 13 per cent, displacing about the same percentage of iron. The ore is in enormous quantities, in one place laid bare so that he crossed over it 30 paces.

A year later, in a report on the mineralogy of Minnesota, Winchell^c said of menaccanite:

This seems to be the principal magnetic mineral which enters into the gabbro and other igneous rocks of the Cupriferos in Minnesota. It is so abundant in the region of Iron Lake, north of Grand Marais, and at Herman, near Duluth, that it has attracted attention as an iron ore. The titanium present is frequently not enough to constitute the mineral, which requires from 30 to 40 per cent. It is sometimes as low as 3 per cent, the mineral then being rather titaniferous magnetite.

Irving^d mentions the same localities. In speaking of the orthoclase-bearing gabbros, he says:

In some of these rocks the titaniferous magnetite forms bunches of such size as to have attracted attention as an iron ore, as, for instance, at Duluth, and again at several points in the interior back of Grand Marais and Beaver Bay. From some of this ore obtained some miles back of Grand Marais I obtained, some years since, over 10 per cent of titanic acid.

In 1887, Winchell^e mentioned the occurrence of titaniferous iron ore in abundance on the shore of Gabimichigama Lake. In a letter to the author dated January 28, 1912, Mr. John G. Howard, of Duluth, writes the following in regard to this same locality: "The ore marked from section 7-64-5 and section 12-64-6 comes from the county line between Cook and Lake, and crosses the line and outcrops in

^a Winchell, N. H., Tenth Annual Report of the Geological and Natural History Survey of Minnesota, 1881, p. 81.

^b Idem, pp. 80-81, 85.

^c Winchell, N. H., Eleventh Annual Report of the Geological and Natural History Survey of Minnesota, 1882, p. 17.

^d Irving, R. D., The copper-bearing rocks of Lake Superior: Mon. 5, U. S. Geol. Survey, 1883, pp. 51-52.

^e Winchell, Alexander, Fifteenth Annual Report of the Geological and Natural History Survey of Minnesota, 1886, p. 167.

Lake County in section 12-64-6, and also in section 7-64 5, Cook County. This is a fine large outcrop and assays as follows: Iron, 56.16; phosphorus, 0.003; silica, 2.40; manganese, 0.40; lime, 0.04; magnesia, 1.35; sulphur, trace; titanium, from none to 6. This deposit shows on surface for over a mile in length and shows lots of clean ore." Mr. Howard also states that there are a number of deposits between this location and Iron Lake, which lies about 18 miles to the east. Another analysis furnished by Mr. Howard comes from a locality still farther west in section 30-63-9, and is as follows: Iron, 55.04; phosphorus, 0.003; silica, 6.20; lime, 0.15; manganese, 0.28; magnesia, 2.28; alumina, 8.85; sulphur, 0.876; titanium, from 2.50 to 19.

Wadsworth,^a in describing the Duluth gabbro, says: "Others, again, have the magnetite abundantly developed, so much so that the grayish-black rock has been designated an iron ore, which has been mined at Duluth." Again he says:^b "In local modifications of gabbro, the magnetite predominates to such an extent over the other minerals that it is mined as an iron ore. The quantity of this ore is very great, and a number of mines exist upon it at various localities, * * * the only apparent limit to it being extensively mined is owing to the titaniferous nature of the ore. * * * These ores generally seem to be titaniferous magnetite, the titanium varying from a minute amount up to 12 per cent or higher."

Winchell again refers to Iron Lake in the sixteenth annual report of the geological and natural history survey of Minnesota. He says:^c

The rim of the lake is mostly massive gabbro. This in places is so strongly charged with magnetite that one might truthfully conceive of the prison lake as iron-bound. The abundance of the magnetite caused attention within a few years to be directed to the region, but investigation showed the ore to be strongly titaniferous.

Describing a point on the north shore, he says:^d

Black sheets of magnetite are seen spreading out in the gabbro in an irregular way. Here and there fragments of the gabbro are involved in it. The appearance is as if the magnetite had existed previously and been introduced into the mass of fluid gabbro and never generally diffused.

Winchell,^e describing the different kinds of iron ore found in north-eastern Minnesota, says:

The third variety of iron ore is also magnetite. It is coarse and has a duller luster than the Animikie ore and is not so strongly magnetic. It is found in many places in the gabbro, which sometimes contains so much of it that it seems to be pure mag-

^a Wadsworth, M. E., Preliminary description of the peridotites, gabbros, diabases, and andesytes of Minnesota: Bull. 2, Geol. and Nat. Hist. Survey of Minn., 1887, p. 49.

^b Idem, pp. 63, 64.

^c P. 304.

^d P. 305.

^e Winchell, H. V., Seventeenth Annual Report of the Geological and Natural History Survey of Minnesota, 1888, pp. 80-81.

netite. This ore almost always contains a large amount of titanitic acid which ruins it for merchantable ore, with only present methods of reduction. Immense deposits of this titaniferous ore are found, and most of them have been purchased from the United States Government in the hope of being able to conduct remunerative mining operations. When a method for reducing titaniferous ores cheaply is discovered, such iron ore will be valuable; but until then it is worthless.

An analysis of a sample of this ore from section 36-63-10, as reported by Mr. C. F. Sidener, is:

	Per cent.
Silica, SiO_2	11.37
Alumina, Al_2O_3	1.32
Magnetic oxide of iron, Fe_3O_4	53.33
Protoxide of iron, FeO	14.42
Oxide of titanium, TiO_2	16.03
Lime, CaO	.10
Magnesia, MgO	2.73
Phosphorus, P.....	.01
Sulphur, S.....	Traces.
	99.31
Metallic iron, Fe.....	49.40

In this same report he says:^a

Speaking of the gabbro on Mayhew Lake, this gabbro contains considerable magnetite. Several claim cabins are located on this gabbro ore. The gabbro in Tucker Lake just west of Mayhew Lake is also magnetic. * * * In the SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 2, 64-3 the gabbro contains parallel bands of magnetite which dip S. 40° and give the rock a decidedly stratified aspect. Some of the beds or bands of magnetite are 4 or 5 inches thick, others only a fraction of an inch.

U. S. Grant, in the report mentioned,^b refers to another locality on Mayhew Lake. He says:

On the end of the little point which is in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 36, the gabbro has changed somewhat, and on the south side of this point it surrounds a large mass of iron ore. This ore seems to be principally magnetite, with a little scattering feldspar, but as it is in the gabbro, it very probably contains a considerable amount of titanium. The exposure of ore was 30 feet wide, and extended for about 300 feet along the shore, rising 15 feet above the water. The contact between the ore and gabbro was found at one place; here the gabbro does not pass into the iron ore by gradually acquiring more magnetite, but there is a sharp and distinct line between the two.

In Bulletin 6 of the Minnesota survey, on the iron ores of Minnesota, four groups of iron ores are recognized, one of which is called the "gabbro titanitic-iron group." This is described as follows:^c

There is certainly no iron ore in Minnesota which is known to exist in larger amounts than this. The explorer in the iron region is continually finding this ore in immense masses, and it has been the cause of many visits by intending purchasers. Fortunately the lithologic characters that surround it are so simple, uniform, and evident that the tyro may discern them. The belt that carries this ore is wide, and it extends

^a Op. cit., p. 105.

^b Op. cit., p. 169.

^c Winchell, N. H., and Winchell, H. V., The iron ores of Minnesota: Bull. 6, Geol. and Nat. Hist. Survey of Minn., 1891, p. 123.

from Duluth to Pigeon Point, constituting, in its culminating topographic points, the summits of the Mesabi Range.

The bulletin^a states further:—

The gabbro titanite-iron group of lithologic characters has been described. It is only necessary to say here that the ore is a black, massive magnetite, generally of coarse, hackly crystalline fracture, and when pure and in large quantities, as it is frequently, it appears in bold and bald knobs, and is dispersed irregularly through the gabbro of the Mesabi Range.

It seems to be only a highly magnetized condition of the structureless gabbro rock itself. This ore was first seen by the officers of the survey at Mayhew Lake, north from Grand Marais. Mayhew Lake is sometimes known as Iron Lake.

This iron is in considerable but unknown quantity at this place, but appears in a similar manner in many places in the vicinity of Mayhew Lake, toward the southwest and west, as well as toward the southeast. This ore may also be seen in the gabbro within the corporate limits of Duluth, where it appears simply as a very highly ferruginous condition of the gabbro, with the other gabbro minerals as its impurities. There is no place within the area of the gabbro sheet where this ore may not exist, as its appearance is entirely fortuitous, but its quality varies from nearly pure magnetite (or menaccanite) to simply magnetitic gabbro.

This report^b also gives three analyses in addition to those already cited, as follows:

Results of analysis of ore from section 36, 65-3 W. (Iron Lake).

[Analyst, Prof. J. A. Dodge.]

Silica.....	20.90
Alumina.....	1.75
Lime.....	Trace.
Magnesia.....	2.63
Titanium binoxide.....	2.23
Phosphorus.....	None.
Protoxide of iron.....	2.01
Magnetic oxide of iron.....	70.29
	99.81
Metallic iron.....	52.46

Results of analysis of iron sand from Black Beach, near Beaver Bay.^c

[Analysts, J. A. Dodge and C. F. Sidener.]

Silica.....	65.17
Magnetic oxide of iron.....	30.06
Protoxide of iron.....	2.23
Dioxide of titanium.....	2.48
Lime.....	Trace.
Magnesia.....	Trace.
Alumina.....	Trace.
	99.94
Metallic iron.....	23.50

^a Op. cit., pp. 135-136.

^b Op. cit., pp. 141-142.

^c The statement is made that the sand is derived chiefly from the decomposition of titaniferous gabbro. Bayley states, however, that the rock of Beaver Bay is not a part of the Duluth gabbro, but probably a part of a sheet or sill intrusive in the Keeweenaw, and occurring at a much higher horizon (Jour. of Geol., vol. 2, 1894, p. 819).

Results of analysis of iron sand from the SW. $\frac{1}{4}$ sec. 33, 61-12, south shore of Birch Lake.

[Analyst, Prof. J. A. Dodge.]

Silica.....	5.19
Alumina.....	2.95
Lime.....	Trace.
Magnesia.....	.35
Phosphorus.....	None.
Titanium dioxide.....	36.77
Metallic iron.....	41.12

Bayley, in discussing the peripheral phases of the great gabbro mass of northeastern Minnesota, speaks of the titaniferous magnetites. He says: ^a

The specimens in the possession of the United States Geological Survey all contain a large proportion of magnetite, which in some cases runs so high as to constitute 90 per cent of the entire rock. These latter rocks have the bright metallic luster of magnetite and usually a finely granular texture. The luster frequently becomes very brilliant and the specimen takes on the peculiar pinkish tinge of ilmenite. A careful inspection of such specimens as seem to be pure ore reveals the presence in them of tiny yellowish-green grains of olivine, but these are so rare that they produce but little impression on the general aspect of the rock. When the magnetite makes up practically its entire body the rock is much jointed, and, consequently, it easily breaks into small irregular or cuboidal fragments, as Winchell has already noted, and these are not unfrequently natural magnets. Tests of magnetites of this kind from the shores of Little Sasaganaga Lake, NW. $\frac{1}{4}$ sec. 7, T. 64 N., R. 5 W., prove them to be very rich in titanium, as was surmised from their pinkish tinge.

The ore and its occurrence were described by Elftman in 1898. In a discussion of the minerals of the gabbro, he says: ^b

Magnetite is scattered throughout the rock. Ordinarily it occurs in small grains usually having perfect crystal outlines. Large irregular areas, making up a large part of the rock, are found in some sections. The proportion increases until the entire rock is made up of this mineral. Chemical examinations show that the mineral is sometimes free from titanium, but usually the latter constituent is present in varying amounts up to 20 per cent.

Elftman gives the following description ^c of the occurrence of the ores:

Small masses of titaniferous magnetite are scattered throughout the gabbro. Extensive masses are known only along the northern border and in the eastern part of the gabbro. These deposits of magnetite are especially numerous in the region between Brule Lake and the northern limit of the gabbro. The ore bodies are found in three belts running east and west. The northernmost follows the boundary of the gabbro. The second runs through the southern part of township 64 north, and the southern or third belt runs south of Brule Lake through the central or southern part of township 63 north.

The magnetite deposits are usually associated with granulitic norite, which is always the slightly older of the two. The norite is considerably broken and traversed by

^a Bayley, W. S., The basic massive rocks of the Lake Superior region: Jour. of Geol., vol. 2, 1894, p. 818.

^b Elftman, A. H., The geology of the Keeweenaw area in northeastern Minnesota: Am. Geol., vol. 22, 1898, p. 140.

^c Op. cit., pp. 145-146.

veins of magnetite extending from the larger masses around its edge. From the main mass of the magnetite stringers and apophyses run several hundred feet into the massive gabbro. Frequently the magnetite occurs in numerous parallel bands several inches to a foot in width, which alternate with bands of the associated gabbro. As many as 25 of these bands have been noticed within a belt 10 feet wide. There are all proportions of minerals between magnetite and the normal phase of the gabbro. The variations of the ore as seen in a shaft 19 feet deep on section 21, T. 63 N., R. 4 W., are as follows: At the surface the rock was composed of solid coarse magnetite stained green with a coating of malachite. The pure magnetite continued downward for 5 feet, when a few grains of chalcopyrite, pyrite, and plagioclase were found. At 7 feet below the surface the magnetite became fine grained, and a small amount of plagioclase and pyrite continued. Olivine appears as bright, yellow grains. Continuing downward the plagioclase and pyrite disappeared and the lower 10 feet of the shaft were in magnetite, with the olivine increasing in proportion.

The ore has a shining black luster, is brittle, and usually coarse grained. Thin sections of the apparently pure ore generally show the presence of small particles of plagioclase, and sometimes of other minerals. * * *

Chemical analyses show quite a variation in the composition of these ores. An analysis by the writer of an ore from sec. 21, T. 63 N., R. 4 W., gave silica, 6.08; alumina, 3.82; lime, 1.69; titanium oxide, 14.73; magnetite, 71; nickel oxide, 2.65; sulphur, trace. The lime and alumina are accounted for by the presence of a triclinic feldspar.

Titanium is sometimes absent. Cobalt, manganese, and chromium are sometimes found in addition to the constituents given in the above analysis. The metallic iron varies from 49 to 60 per cent. These extensive magnetite deposits at present afford the only ores from the gabbro of probable economic value.

After describing the character of the titaniferous ore deposits in the gabbro, Clements^a says of them:

The injurious effect of the titanium in rendering the magnetite unmarketable would of course apply to these titaniferous magnetite bodies whatever their size. However, so far as we know, up to the present time no published description has been given of any large continuous masses of the practically pure titaniferous magnetite.

The following recent statement concerning these ores by Van Hise and Leith^b is in the nature of a summary of existing knowledge, and for that reason is quoted in full:

The great gabbro mass of Lake and Cook Counties, Minn., contains much magnetite, both disseminated and segregated into ore deposits. Complete gradation may be observed between gabbro carrying little magnetite and magnetite carrying little of the ferromagnesian constituents and feldspar. The known deposits are extremely irregular, with gradations between themselves and the gabbro and containing within themselves much gabbro material. They weather very much like the gabbro and might be easily unnoticed on the weathered surface. There has been little exploration for these ores. A few drill holes have been sunk in the region south of Gunflint Lake, some of them revealing depths of ore aggregating several hundred feet. The known deposits seem to be distributed in irregular zones roughly parallel to the north or basal margin of the Duluth gabbro.

^a Clements, J. M., The Vermillion iron-bearing district of Minnesota: Mon. 45, U. S. Geol. Survey, 1903, p. 421.

^b Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: Mon. 52, U. S. Geol. Survey, 1911, p. 561.

The composition of the ore averaged from 3,560 feet in 14 drill holes is 48.8 per cent iron. The range is from 54 to 20 per cent. The high titanium content renders the ores of doubtful value for the present.

Where the gabbro comes into contact with the iron-bearing Gunflint formation both formations carry magnetite so similar in texture that it is difficult to tell one from the other. However, on analysis the gabbro magnetite is found to be titaniferous, whereas that of the Gunflint formation is not titaniferous. This fact seems to argue against any considerable transfer of material from the gabbro to the iron-bearing formation during its alteration.

The titaniferous magnetites of northeastern Minnesota are direct magmatic segregations in the Duluth gabbro, according to all of the geologists who have studied them, including Irving, Merriam, Bayley, Grant, Winchell, Clements, Van Hise, Leith, and others. The complete gradation from gabbro with a small amount of original magnetite to a magnetite with small amounts of amphibole and other gabbro minerals can be seen in almost any part of the titaniferous magnetite deposits. It is scarcely necessary to repeat the detailed petrologic evidence so fully given by the writers named.

Evidence is given elsewhere for the intrusive character of the Duluth gabbro. It cooled far beneath the surface, where there was not easy escape for its solutions. This fact is taken to explain its retention of its iron oxide. It has been argued under an earlier heading that where basic rocks of similar composition reached the surface large quantities of iron escaped and became available for ordinary sedimentary deposition.

The area underlain by the Duluth gabbro is for the most part an uninhabited region of woods and lakes, where the only means of travel is by canoe. It was impossible and also useless for the purposes of this report to have visited the whole of such a vast area. It was also apparent from the literature that the actual importance of these deposits with respect to size and iron content was open to doubt. It was decided, therefore, to visit the most promising region within the gabbro area. Judging from the published descriptions this seemed to be the area about Iron Lake. Responses to inquiries made of numerous geologists, prospectors, and others who were familiar with the area also pointed to the Iron Lake region as having the most promising showing of ore. It was further learned that considerable drilling had been done there some years ago, and the drill records and detailed maps were very kindly placed at the writer's disposal. Consequently the region about Iron Lake was selected as the one to be visited, and the following paragraphs are an account of the observations made there.

IRON LAKE REGION.

A week was spent in this region with Nicholas Probek, of North Lake, as guide. The familiarity of Mr. Probek with the country made possible the careful examination of a large area. The area examined was the country adjacent to Tucker, Iron, Portage, and Poplar Lakes. It is a narrow belt extending on both sides of the town line between T. 64 N. and 65 N., and from the middle of R. 1

W. to the middle of R. 3 W. For convenience of discussion the region is considered under subheadings corresponding to the lakes above mentioned.

TUCKER LAKE.

Tucker Lake is a narrow lake with its axis lying nearly east-west. It extends from near the western edge of section 4 to near the middle of sec. 1, T. 64 N., R. 3 W. Its eastern end is divided into a northern and southern arm by a narrow peninsula. Its outlet is at about the middle of the north shore.

Along the north and south shores of the lake in the neighborhood of the outlet, and for some distance along the outlet, are almost continuous rock exposures. The prevailing rock is the normal gabbro, in many places with considerable feldspar, so that it has a light color. Magnetite occurs throughout the rock in sparsely disseminated grains. The most prominent femic constituent is the pyroxene, which has usually to a great extent undergone uralitization. Biotite is locally abundant in intimate association with the pyroxene, and seems to be a secondary product. At several places the normal coarse gabbro gives way to a fine-grained rock of brownish-gray color. Thin tablets of feldspar, 1 cm. long and less than 1 mm. thick in parallel arrangement, give this rock at times a schistose appearance. Certain phases of this rock are rather heavy and weather with a black surface suggesting magnetite. A careful examination of this rock, which has been called ore, shows that it contains only a small amount of ore minerals. At only one point, on the south shore, a little west of the outlet, is there anything that could be called ore. The gabbro here contains a small segregation of ore 25 feet long. The greater part of this is very lean, being nothing more than gabbro in which the feldspar has become subordinate and the pyroxene the most prominent constituent. Magnetite is present in considerable amount, and makes up a rock which at first sight appears to be good ore. A closer examination reveals a large quantity of black augite and considerable olivine. A polished section of one of the richest pieces of this ore showed that less than half consists of ore minerals, and this is almost entirely ilmenite.

A half mile north of the outlet at Tucker Lake, in the SE. $\frac{1}{4}$ sec. 34, T. 65 N., R. 3 W., is an opening in an ore body. The pit has a length of 125 feet along the outcrop, which is here in the form of a ledge. Several hundred tons of ore have been blasted loose and the exposures are very good. The outcrop of ore can be traced about 100 feet east of the pit, beyond which it is covered with drift. To the west of the pit it is entirely covered. This ore body ranges in width from 8 to 10 feet; and passes into gabbro on each side. The ore itself is rather lean, and grades rapidly into normal gabbro, so that a sharp distinc-

tion can usually be made between gabbro and ore. Within the ore body are small inclusions of gabbro with boundaries so distinct against the surrounding ore as to have the appearance of real included fragments of the gabbro country rock and not segregations of the gabbroitic material in the ore. The relations of the contact and these inclusions would suggest that the segregation did not take place where the ore body is now found, but that the ore body was squeezed into its present position, perhaps while the gabbro was still in a molten or viscous state. Between this pit and the shore of Tucker Lake are several exposures showing schlierenlike ore bodies of still smaller size whose relations to the country rock suggest a similar origin. Northwest of the pit is a ledge of gabbro with a small band of lean ore running through it. In the leaner parts of the ore the pyroxenes are the most prominent gangue minerals; in the rich part, consisting almost entirely of the ore minerals, olivine is the most abundant gangue. Analyses of ore from this property are said to have shown about 18 per cent Ti.

Along the north shore of the north arm of Tucker Lake are a number of exposures of gabbro showing considerable iron. The ore occurs in small ferromagnesian-rich areas of the gabbro. These areas are characterized by the feldspar becoming subordinate in amount accompanied by a rapid increase in the amount of pyroxene. At the same time olivine and magnetite become prominent. This rock grades over into ore by magnetite, and, to a less extent, olivine, becoming more abundant at the expense of the pyroxene. The decrease in the amount of pyroxene is, however, more apparent than real as the dark pyroxene is difficult to recognize in the magnetite, whereas the clear yellow olivine stands out strongly against the black magnetite. At one point the ore swarms with fine needles of apatite. Here again polished surfaces show that the ore is not nearly so rich as would appear from hand specimens, and even the richest pieces do not show much more than 50 per cent of ore minerals. Less than 100 yards northeast of the end of this arm of the lake is a cut 8 feet wide, 10 feet deep, and 25 feet long. The best ore seen along this shore occurs there, but there is a rapid alternation of good and bad ore, so that the average of the rock as obtained in mining would be rather lean.

Exposures of highly magnetitiferous gabbro grading into ore occur on the peninsula between the two arms of Tucker Lake and along the north shore of the southern arm to the narrows, draining a small lake that lies to the east and is known as "The Pond." The nature of these outcrops is the same as those on the north shore of the north arm of the lake. The ore bodies, wherever their width is exposed, are narrow, usually not more than 12 feet in width, and their length is not more than 100 to 200 feet, being considerably less in most

cases. Where their limits are not exposed on account of the drift covering, in most cases other outcrops of gabbro near by show that their size is no greater. On account of the dark-colored gangue minerals, hand specimens always appear much richer than is actually the case; and specimens of seemingly good ore are seen on polished surfaces to be rather lean. Apatite is abundant in some of these ores. Analyses at different depths of a diamond-drill core through one of these ore bodies showed the following composition of the ore:

Results of analyses of diamond-drill core from the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 2, T. 64 N., R. 3 W.

Depth.....	30 feet.	60 feet.	100 feet.	150 feet.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Iron peroxide.....	35.00	35.14	35.00	33.71
Iron protoxide.....	32.92	32.28	32.28	33.41
Alumina oxide.....	.51	.48	.40	.26
Manganese oxide.....	2.86	2.89	2.26	2.12
Chromium oxide.....	.06	.08	.012	.01
Vanadium oxide.....	Trace.	Trace.	Trace.	Trace.
Magnesia carbonate.....	1.20	1.25	1.82	1.16
Calcium carbonate.....	2.16	2.07	2.24	1.14
Phosphorus.....	.012	.012	.008	None.
Sulphur.....	.01	.008	None.	None.
Titanic acid.....	1.25	1.28	.616	.17
Silica.....	24.00	24.50	26.00	26.00
Metallie iron.....	50.50	50.00	50.00	50.00

The titanium in these analyses is very low, the average being 0.83 per cent TiO_2 . This is not representative of the ore in this vicinity, however, as polished sections show considerable ilmenite. The average iron content in terms of metallic iron is 50.13 per cent. Some of this iron occurs in the femic minerals of the gangue and is not present in the ore minerals. The maximum percentage of magnetite the ore could contain is that corresponding to the percentage of iron peroxide given in the analyses. Assuming all of the peroxide of iron to be present in the form of magnetite, the percentage of iron contained in the magnetite would be 36.75, 36.90, 36.75, and 35.40 per cent, respectively, an average of 37.20 per cent.

At the eastern end of the series of outcrops being discussed, along the shore of the narrows mentioned above, is a ledge of rock 300 feet long, at the eastern end of which is a small pit about 10 feet deep. The western end of this outcrop consists of the normal coarse-grained gabbro; toward the east increasing amounts of magnetite occur, until the richest ore is encountered at the pit. This ore differs from the ore previously described in that the feldspar and ferromagnesian minerals are present in the same ratio as in the normal gabbro. The change in composition of the rock is due wholly to the increase in percentage of magnetite. The feldspar has assumed, however, a distinct tabular habit, giving the rock a coarse diabasic texture. There is also a tendency to parallel arrangement on the part of the feldspar crystals which gives the rock a schistose appearance in

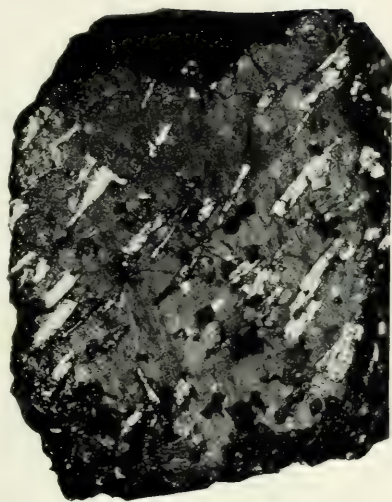
places. Very little good ore occurs here and most of it is too lean to be called ore. A thin section of the ore showed feldspar and femic minerals about equally abundant. The femics are augite and olivine with a little biotite. The biotite seems to be principally secondary, occurring around the edges of the magnetite grains.

This series of outcrops crosses the narrows and continues eastward south of "The Pond" nearly to the line between range 2 and range 3, beyond which the gabbro contains little iron. Outcrops of ore bearing gabbro are numerous, but the extent of each is limited. The prevailing ore is of the feldspathic variety last described, though many outcrops are of better grades. High-grade ore occurs only as narrow seams and stringers in the lean ore. A thin section of the rich ore consisting of about one-third gangue had olivine as the most abundant gangue mineral; it also had considerable augite. Besides these, a little plagioclase and a few flakes of mica were present. In the leaner phases, however, the most striking feature is the tabular crystals of plagioclase. This ore differs decidedly from the Rhode Island ore with its phenocrysts of tabular feldspar. The groundmass is of much coarser grain, so that the feldspar and other constituents are more nearly of the same order of magnitude; and the feldspar crystals are far more numerous, giving the ore a pronounced diabasic texture, which the Rhode Island ore does not possess. The only ore resembling it is that from Iron Mountain, Colo.; but in the latter the feldspar is not so prominent nor the diabasic effect so marked. Plate VIII, A, shows a rich piece of this Iron Lake ore with the large tabular crystals of feldspar; Plate VIII, C, shows the Iron Mountain ore in which the feldspar tablets are more abundant, but smaller. Analyses of different sections of a diamond-drill core through a body of this ore showed the following composition:

Results of analyses of diamond-drill core from the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 1, T. 64 N., R. 3 W.

Depth.....	55 feet.	65 feet.	75 feet.	85 feet.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Iron peroxide.....	35.61	46.14	35.14	41.43
Iron protoxide.....	30.00	21.53	32.40	24.05
Alumina oxide.....	2.70	4.89	4.00	2.20
Manganese oxide.....	1.75	2.60	3.20	.20
Chromium oxide.....	1.11	1.01	2.05	1.50
Vanadium oxide.....	1.006	.906	1.03	2.60
Magnesia carbonate.....	1.70	1.20	.06	1.54
Calcium carbonate.....	2.50	.056	.04	.05
Phosphorus.....	.002	.007	.002	.002
Sulphur.....	.006	None.	None.	.003
Titanic acid.....	6.50	None.	8.25	5.75
Silica.....	17.11	21.65	13.81	20.67
Metallic iron.....	49.20	49.30	48.40	48.20

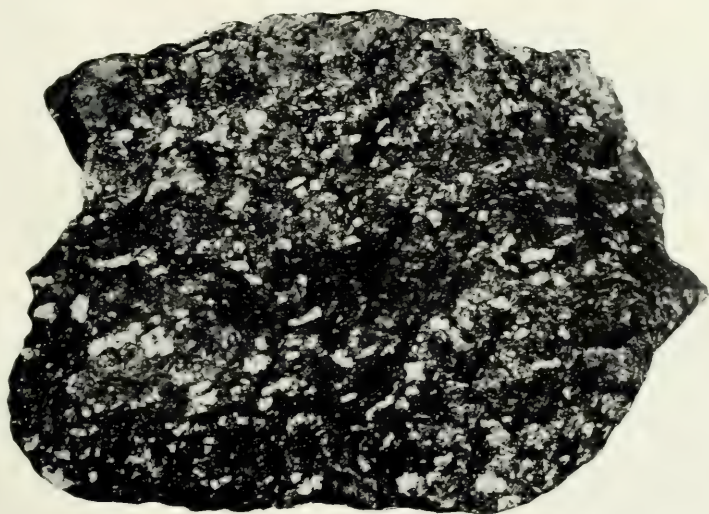
The titanium content is rather low, the average TiO_2 content of the four analyses being 5.13 per cent. The average of the metallic iron given in the analyses is 48.78 per cent. It must be remembered,



A. IRON LAKE, MINN., ORE. ($\times 1\frac{1}{2}$)



B. POPLAR LAKE, MINN., ORE. ($\times 2$)



C. IRON MOUNTAIN, COLO., ORE. (NATURAL SIZE.)

however, that some of this iron is present in the ferromagnesian gangue minerals. If we assume all the peroxide of iron to be present in the form of magnetite, the metallic iron contained in the magnetite would be 37.39, 48.45, 36.90, and 43.50 per cent, respectively, an average of 41.56 per cent.

IRON LAKE.

In addition to the ore outcrops just described, at the western end of Iron Lake and along the south shore toward that end there are others farther east along the lake, but only one or two of these is here described.

Extending across a small island southeast of the portage from Loon Lake is a band of ore 200 yards long and 20 to 30 feet wide. Gabbro is exposed on both sides of the ore body. The ore is for the most part lean. Along the north shore, east of the outlet, is a series of outcrops of ore. Some of these show very good ore, but each is of small size, passing within short distances into gabbro. One of the larger of these outcrops was traced for over 200 yards, but its width averaged only 12 to 15 feet. Even the high-grade ore contains inclusions of lean ore and gabbro; and, in other cases, the rock consists merely of gabbro with numerous bands and stringers of ore running through it. A specimen of the high-grade ore from this locality analyzed 53.30 per cent Fe, 24.30 per cent TiO_2 .^a

PORTAGE LAKE.

On Portage Lake little ore was observed. The most prominent outcrop is on the north shore of the north arm of the lake, east of the portage from Iron Lake. At this point there can be traced, for a distance of about 100 yards, a series of small ore outcrops within an area of gabbro. The ore is of the feldspathic variety and contains considerable gangue.

POPLAR LAKE.

Outcrops are abundant along the entire north shore of Poplar Lake, and many exposures of ore were seen. In all cases where the exposures were continuous enough the ore bodies were seen to be of small size. The character of the ore showed considerable variation from place to place. In some exposures the feldspathic ore occurred, in others the ore with the femic minerals. Thin sections showed considerable apatite throughout the ore, and some of the crystals of apatite are large enough to be easily recognized in the hand specimens. In addition to the ore bodies, the gabbro along this shore contains considerable magnetite scattered through it as an accessory constituent.

^a Analysis computed from analyses of concentrates and tailings made by A. C. Fieldner, of the Bureau of Mines.

COMPOSITION OF THE ORE.

The ore has been described with sufficient detail in the discussion of its occurrences, so that only a brief résumé is here given. Probably the most striking feature of the ore is the great variation it presents both in appearance and composition. The high-grade ore with little gangue tends to be compact and massive, rather than granular. Of the leaner ores, there are the two varieties that can be designated according to the most prominent gangue minerals, the feldspathic and the femic. The femic ores are medium grained and possess no marked characteristics. The feldspathic ores tend to be somewhat coarser grained and are characterized by the coarse diabasic texture produced by the lath-shaped feldspar crystals.

A most interesting feature is the chemical composition of the ore, on account of the unusual behavior of the titanium content. The available results of analyses are tabulated below:

Results of analyses of Minnesota ores.

Constituent.	1	2	3	4	5	6	7	8	9
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	58.48	56.16	55.04	49.83	52.46	23.50	41.12	51.40	53.30
TiO ₂	20.15	0-10	4.17-31.67	16.03	2.23	2.48	36.77	14.73	24.30
SiO ₂	2.02	2.40	6.20	11.37	20.90	65.17	5.19	6.08	.....
Fe ₃ O ₄	80.78	.....	.....	53.33	70.29	30.06	.....	71.00	.....
Fe ₂ O ₃.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
FeO.....	.....	.....	.....	14.42	2.01	2.23	.....	.....	.....
Al ₂ O ₃	2.68	.....	8.85	1.32	1.75	Trace.	2.95	3.82	.....
Cr ₂ O ₃	2.40	.....	.....	.....	.....	.....	.....	.....	.....
Mn ₂ O ₃.....	.....	.57	.40	.....	.....	.....	.....	.....	.....
CaO.....	Trace.	.04	.15	.10	Trace.	Trace.	Trace.	1.69	.....
MgO.....	.....	1.35	2.28	2.73	2.63	Trace.	.35	.....	.....
NiO.....	.....	.....	.....	.....	.....	.....	.....	2.65	.....
P.....	.013	.003	.003	.01	.....	.....	None.	.....	.....
S.....	.....	Trace.	.876	Traces.	None.	.....	Trace.	.....	.....
	.....	.....	.....	99.31	99.81	99.94	.....	.....	.....

Constituent.	10	11	12	13	14	15	16	17
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Iron peroxide.....	35.00	35.14	35.00	33.71	35.61	46.14	35.14	41.43
Iron protoxide.....	32.92	32.28	32.28	33.41	30.00	21.53	32.40	24.05
Alumina oxide.....	.51	.48	.40	.26	2.70	4.89	4.00	2.20
Manganese oxide.....	2.86	2.49	2.26	2.12	1.75	2.60	3.20	.20
Chromium oxide.....	.06	.08	.012	.01	1.11	1.01	2.05	1.50
Vanadium oxide.....	Trace.	Trace.	Trace.	Trace.	1.006	.906	1.03	2.60
Magnesia carbonate.....	1.20	1.25	1.82	1.16	1.70	1.20	.06	1.54
Calcium carbonate.....	2.16	2.07	2.24	1.14	2.50	.056	.04	.05
Phosphorus.....	.012	.012	.008	None.	.002	.007	.002	.002
Sulphur.....	.01	.008	None.	None.	.006	None.	None.	.003
Titanic acid.....	1.25	1.28	.616	.17	6.50	None.	8.25	5.75
Silica.....	24.00	24.50	26.00	26.00	17.11	21.65	13.81	20.67
Metallic iron.....	50.50	50.00	50.00	50.00	49.20	49.30	48.40	48.20

Of these analyses the average Fe content is 49.23 per cent and the average TiO₂ content 10.96 per cent. The average titanium content is somewhat lower than the average for titaniferous magnetites. It would be fairer, however, to take an average of analyses 10, 11, 12,

and 13 and count that as one analysis, and the same with 14, 15, 16, and 17, as they represent only different parts of a drill core. If the analyses are averaged on this basis, there is practically no change in the iron, but the average titanium content becomes 13.23 per cent TiO_2 , a percentage that is more nearly the normal. The unusual feature of this ore is the wide range shown by the titanium. In general, the titanium present in a given deposit is fairly constant. In the case of these ores, the percentage of titanitic acid ranges from zero to nearly 37 per cent. Phosphorus is present in the form of apatite in considerable amount locally, but averages low. Another point of note is the absence of spinel in the thin and the polished sections examined.

METALLOGRAPHIC DESCRIPTION OF THE ORES.

Polished sections of the ores show considerable uniformity as regards the intergrowth of magnetite and ilmenite. Otherwise, as one would expect from the description of the ores, there is considerable variation. As is generally the case, polished sections of the femic ores show more gangue than is apparent in the hand specimens; and there is every gradation from pure ore wholly lacking in the essential constituent in the gabbro to rock that can be called nothing more than magnetite-bearing gabbro.

The ratio of magnetite to ilmenite also varies from ore in which ilmenite is almost lacking to ore in which magnetite is almost lacking.

The characteristic of most of the polished sections is the minute association of the titanium in the magnetite with the magnetite. Very little dull-black magnetite occurs. Most of it shows a dull-gray mottled effect to a bright iridescent effect. These effects pass over, however, by gradual transitions, to minute networks, and these into coarser networks. Also by increasing the magnification sufficiently seemingly continuous iridescent surfaces can be resolved into a close minute network of ilmenite against a black background of magnetite. Plate VII, *B*, shows an area of gangue and one of magnetite with ilmenite intergrowths. Adjacent to the gangue area, the ilmenite is so closely intergrown as to form a nearly continuous bright surface. This passes over into a delicate network. Plate IX, *A*, shows a well-developed minute delicate network, which with less magnification gives the magnetite grain a semilustrous appearance.

Though these minute intergrowths are the prevailing ones, other forms also occur. Some of the sections show beautifully developed network of the normal coarseness. Others show very coarse open network passing over into areas containing only isolated thick lamellæ. Plate VIII, *B*, shows an ore of an unusually coarse network. The thin border of ilmenite about the outline of magnetite grains, as illustrated in Plate IV, *A*, also occurs.

POSSIBILITIES OF UTILIZATION.

Deposits of titaniferous magnetite are very numerous in north-eastern Minnesota, but as a general proposition it may be stated that the high-grade deposits are too small and the large deposits too lean to work.

To utilize the large deposits magnetic concentration would be necessary, but the nature of the ore is such as not to promise satisfactory results. From deposits in which nearly all of the ore consists of ilmenite, considerable titanium could be removed, but the concentrates would form only a small part of the original material. The ore of other deposits in which the magnetite forms a considerable percentage of the ore is usually swarming with the minute inclusions of ilmenite just described. Any considerable diminution of the titanium content in such ore is out of the question. Below are presented results of a separation made of a specimen showing only few grains of ilmenite and bearing magnetite that exhibited the dull, mottled, and bright iridescent surfaces characteristic of the ore from the Iron Lake region.

Results of magnetic concentration of Iron Lake ore.

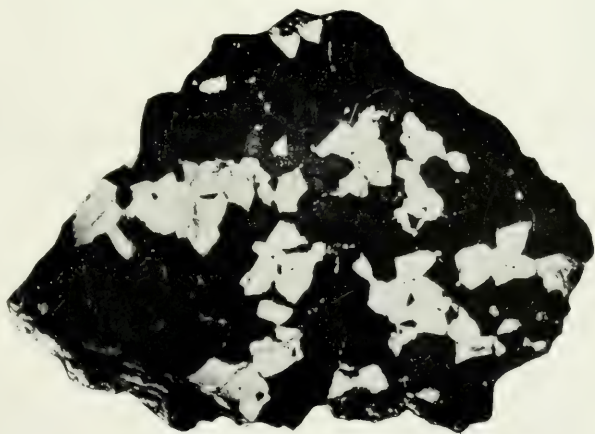
	Un-screened ore.	Ore through 50-mesh, over 100-mesh. ^a		Ore through screen finer than 100-mesh. ^b
		Magnetic.	Non-magnetic.	Magnetic.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Quantity.....		93.3	6.7	92
Fe.....	53.30	54.93	30.59	54.13
TiO ₂	24.30	23.15	40.37	23.53
^a 38.5 per cent.		^b 61.5 per cent.		

These results confirm the intimate relation of magnetite and ilmenite brought out by the metallographic study.

In addition to the disadvantages of these deposits already mentioned, their inaccessible location must also be taken into consideration.



A. TUCKER LAKE, MINN., ORE. ($\times 60$.)



B. IRON MOUNTAIN, WYO., ORE. ($\times 2$.)

WYOMING.

IRON MOUNTAIN.

Iron Mountain is situated in the southeastern part of Wyoming, 20 to 25 miles northeast of Laramie and 9 miles west of Iron Mountain, on the Colorado & Southern Railroad. A second similar, but smaller, deposit occurs on the Shanton ranch, about 5 miles to the southwest. The two localities can be reached by taking the Sibylee stage from Laramie and stopping at Wayside. The Shanton occurrence lies about 3 miles from Wayside, and Iron Mountain about 8 or 9 miles, by trails which are easy to follow. Iron Mountain can be as readily reached from Iron Mountain station.

The occurrence of magnetic iron ore at Iron Mountain has been known for a great many years, and numerous accounts, more or less complete, have been given of the deposit.

Stansbury ^a as early as 1853 mentioned the occurrence of immense numbers of rounded black nodules of magnetic iron ore which seemed of unusual richness in the bed of Chugwater Creek and on the side of the adjacent hills.

In 1870, Hayden ^b called attention to the deposits in the following words:

Near the sources of the Chugwater are some very rich iron mines, which may prove of great value to the country in the future. The fact of their existence has been known for some years, but no definite knowledge of them has been given to the world. * * *. In the winter of 1859-60, while attached to the exploring expedition of Gen. W. F. Reynolds, I made a trip to the sources of the Chugwater, and found great numbers of these worn masses of iron ore; but not until a comparatively recent period were they traced to their source in the mountains. During the construction of the Union Pacific Railroad some of the engineers visited the mines and spoke of their future value. In the summer of 1868 I had an opportunity of examining this region in company with Dr. Latham and Judge Whitehead, of Wyoming, and found the mines much richer and more extensive than had previously been supposed. We commenced our examination in the valleys of the smaller branches of the "Chug" as they emerge from the mountains, and found that the stray masses of iron ore were confined to one of them. Following the branch up into the range we soon came to the ore beds themselves, which we found to be interstratified among the red feldspathic granites which compose the nucleus of the range. The ore beds incline in the same direction with the granites, and have the same joints and cleavage, and the examples of slickensides are numerous. They are not continuous, and are confined to a restricted area, yet Mr. Whitehead traced one of the beds a distance of over $1\frac{1}{2}$ miles. The ore is located much like that in the Lake Superior region, and is probably of the age of the Laurentian rocks of Canada. The quantity of ore in this locality appears to be unlimited. Thousands of tons have been washed down into the valley of the "Chug" and distributed among the superficial drift. As we leave the ore beds themselves these stray masses are larger and more angular, and as we pass down the "Chug" they dwindle to minute pebbles

^a Stansbury, Howard, Exploration and survey of the valley of the Great Salt Lake of Utah, Washington, 1853, p. 266.

^b Hayden, F. V., Preliminary report of the United States geological survey of Wyoming and portions of contiguous territory, 1870, p. 14.

and disappear. Mr. J. P. Carson, of New York, an assistant in the survey of 1868, made the following analysis of this ore, at the school of mines, Columbia College:

Sesquioxide of iron.....	45.03
Protoxide.....	17.96
Silica.....	.76
Titanic acid.....	23.49
Alumina.....	3.98
Sesquioxide of chromium.....	2.45
Sesquioxide of manganese.....	1.53
Lime.....	1.11
Oxide of zinc.....	.47
Magnesia.....	1.56
Sulphur.....	1.44
Phosphorus.....	Trace.
	99.78
Fe.....	45.49

King ^a briefly refers to and Hague ^b describes the occurrence of a gabbro consisting essentially of labradorite and diallage which protrudes the granitoid rocks in the form of low irregular-shaped domes and knolls east of Iron Mountain and Chugwater and Horse Creeks. A microscopic description of this rock is given by Zirkel.^c Hague does not seem to have realized, however, that this rock forms the wall rock of the ores, as he describes the deposit as follows: ^d

Iron Mountain, to which reference has already been made, is a mass of titaniferous iron, or ilmenite, and is situated just north of the Chugwater Creek, about 1½ miles above the point where the stream leaves the hills. The mountain rises about 600 feet above the stream bed, is irregular in form, but has a somewhat oval-shaped outline. It occurs intercalated in the granite, standing nearly vertical, with the walls in places sharply defined; this is the case in the canyon, where the dark iron body resembles a broad dike, which rises to the top of the canyon wall. Frequently large masses of granite are nearly incased in the iron, and again the iron body puts out into the surrounding granite. The main deposit of iron is nearly a quarter of a mile in length, with a strike a little to the west of north and east of south. To the north the main deposit terminates somewhat abruptly; but southward it crosses the canyon, and may be traced cropping out through the granitoid rocks with the same general strike for nearly 2 miles, in the direction of Pebble Creek. These outcrops vary much in size, mostly mere narrow seams and small irregular patches of iron, which disappear in the surrounding granite. Still farther to the south, just above Horse Creek, considerable deposits again make their appearance, but much smaller than Iron Mountain, and, like the latter, have been held for valuable mineral bodies; they are probably only a continuation of the larger one. The ilmenite occurs chiefly as a compact massive deposit, iron-black in color, with a submetallic luster. It is frequently found, however, with a coarse granular structure. It is accompanied by small amounts of magnetite and hematite, which decompose and give portions of the mass a brownish-red appearance. Prof. O. D. Allen, of Yale College, examined specimens of the Iron Mountain ore, and found it to contain a mixture of ferrous and ferric oxide, which gave 50.83 per cent of metallic iron, combined with 23.32 per cent of titanic acid.

^a King, Clarence, United States geological exploration of the 40th parallel, vol. 1, 1878, p. 27.

^b King, Clarence, op. cit., vol. 2, 1877, p. 13.

^c King, Clarence, op. cit., vol. 6, 1876, pp. 107-109.

^d King, Clarence, op. cit., vol. 2, 1877, pp. 14-16.

Other samples of the ore, analyzed by Prof. Richards, of the Institute of Technology in Boston, gave the following results:

Ferrous oxide.....	24.55
Ferric oxide.....	48.97
Titanic acid.....	23.18
Sulphur.....	.03
Residue insoluble in acid.....	2.15
	98.88
Metallic iron.....	53.33

Samples of the coarse granular variety, collected from the deposits south of Iron Mountain, yielded Mr. R. W. Woodward the following:

Metallic iron.....	34.29
Titanic acid.....	49.47

All the samples examined gave a very high, although a varying, amount of titanic acid.

This high percentage of so refractory a substance as titanic acid renders the vast deposits of iron of but little use for practical purposes in iron smelting, which is to be regretted, as the beds in the Laramie Hills could be easily mined, and are so well located in reference to a market and the known resources of iron in Wyoming are so limited.

An account in the Tenth Census is quoted direct from Hayden's description.^a

The next mention of the deposit is made by Knight,^b who gives the following results of analysis:

Results of analysis of Iron Mountain ore.

	Percent.
SiO ₂	1.21
TiO ₂	22.43
Fe ₂ O ₃	47.21
FeO.....	25.80
S.....	1.14
	97.79
Fe.....	51.72

Kemp^c reviews the information available in 1899. Commenting on Hague's description, he says that the relations strongly suggest an intruded origin, and that "granite is an unusual wall rock for titaniferous magnetites, but gabbro, it is interesting to note, occurs in the immediate vicinity." He also mentions a rock obtained from Prof. Knight labeled the wall rock of the titaniferous ores which in thin section is a typical gabbro consisting mostly of labradorite^d and says: "Olivine gabbro would be a much more natural

^a Tenth Census, 1886, vol. 15, p. 485.

^b Knight, W. C., Bull. 14, Univ. of Wyoming Exp. Station, 1893, p. 177.

^c Kemp, J. F., A brief review of the titaniferous magnetites: Sch. of Mines Quart., 1899, pp. 352-355.

^d Hill, B. F., Notes on a set of rocks from Wyoming collected by Prof. Wilbur C. Knight, of the University of Wyoming: Sch. of Mines Quart., vol. 20, 1899, p. 364.

wall rock than granite, and if it is the wall rock in some of the exposures, it would establish the kinship of the ore with the gabbro, and kinship that anyone familiar with the ores of this type would at once believe and assume." Kemp further calls attention to the notable percentage of zinc in the ore as determined in Carson's analysis cited by Hayden, and compares it with the Rhode Island ore in this respect. Lindgren^a also calls attention to the fact that the presence of zinc is unusual in titanomagnetites.

Lindgren's paper contains the first definite statement of the character of the deposit, and the next four paragraphs are quoted from it.

Most of the deposits of titanic iron ore form irregular masses or fairly sharply outlined streaks in gabbro, or still more commonly in anorthosite (labradorfels). Distinct dikes, undoubtedly indicating separate igneous injection of molten magma of titanic iron ore, have, however, also been described by Kemp from the Calamity Brook district in the Adirondacks, and by Vogt from near Ekersund, Norway, and the locality in Wyoming is chiefly interesting as belonging to this type.

The rocks prevailing here are chiefly Paleozoic limestones and sandstones, in rolling folds, and these continue for 6 or 7 miles up Chugwater Creek. The dips here become steeper and the underlying pre-Cambrian rocks appear. As far as my observations went they consist exclusively of a labradorite rock of coarse grain which forms rough gray outcrops. The rock can scarcely be called a gabbro, for the pyroxene grains are very sparingly distributed. It contains very little magnetite or ilmenite. Going up 1 mile farther, the chief deposit is encountered; it crosses the canyon of the Chugwater as a solid dike 100 to 200 feet wide, and can be seen extending up several hundred feet in elevation on both sides of the creek. The mass is said to be traceable for half a mile north and south of Chugwater Creek. The amount of iron ore in sight is most remarkable. The contacts are not exposed to the best possible advantage, but have the appearance of being sharp and well defined. The black titanic iron ore seems entirely pure and free from accompanying minerals; at least a search along the base of the outcrop revealed no other constituents of the mass.

About 400 feet below the main deposit there is exposed on the southern wall of the canyon a smaller dike only about 10 feet wide. The contacts are well exposed and show a medium-grained gray labradorite rock abutting sharply against the dike of titanic iron ore. The dike does not continue on the north side of the canyon, the bottom of which is filled with considerable débris. The greater part of the width of the dike is composed of massive titanomagnetite; but adjoining the western contact the iron ore for a width of 1 or 2 feet contains large, imperfect crystals of olivine embedded in a cementing mass of the black mineral. This association of olivine and titanomagnetite is somewhat unusual; Prof. Vogt, in fact, declares that it is not known to occur (*Z. f. Prakt. Geol.*, 1900, p. 292) in the differentiated ores. The black mineral immediately adjoining the olivines contained, upon qualitative test, a large amount of titanium.

Evidently the points where Mr. Hague saw the deposits were not the same as the locality here described, for the dike, as noted, extends over a considerable distance. The only granitic rock observed at the place described was a small, dikelike mass of fine-grained biotite granite on the north side of the canyon, nearly opposite the smaller dike of iron ore.

On November 21, 1904, Kemp presented an abstract of a paper on "The Titaniferous Magnetite in Wyoming"^b before the New York

^a Lindgren, W., A deposit of titanic iron ore from Wyoming: *Science*, vol. 16, 1902, pp. 984-985.

^b *Amer. Geol.*, vol. 25, 1905, p. 64.

Academy of Sciences, which appeared the following winter in the *Zeitschrift für praktische Geologie*.^a This paper agrees substantially with the views expressed by Lindgren and describes the occurrences in greater detail. The following abstract gives the essential features of the paper:

The geology of the region is roughly indicated in figure 1. The anorthosite belt extends in a northeasterly direction for a distance of nearly 20 miles without showing any appreciable variations. A plagioclase of the composition bytownite-labradorite makes up almost the entire rock. As accessory constituents occur monoclinic pyroxene, a little hornblende, some chlorite, a little calcite, and a few grains of titaniferous magnetite. The anorthosite is cut by granite dikes of granophyric texture, which seem to be somewhat more resistant to erosion and stand out at a height of about 1 meter above the anorthosite. Two such dikes cut the ore body on Iron Mountain. One of these is a biotite granite consisting of microcline, quartz, biotite, and a little plagioclase. Titaniferous magnetite occurs at two localities. One of these is at the Shanton ranch, about 6 miles southwest of Iron Mountain, where the ore outcrops in the form of a black wall above its surroundings. The largest ore body has a length of 500 meters and a width varying from 25 meters to zero, with an average width of 6 meters. The analysis made by Woodward and cited by Hague may be of a sample from this occurrence.

A careful examination of the outcrop failed to reveal any mineral other than the magnetite, which shows a smooth polished surface as a result of the sand and dust blown over it by the violent winds. Thin sections of the ore reveal the presence of many inclusions of green spinel, which suggests the magnetite spinelite of Routivara^b and the mines at Peekskill on the Hudson.^c

The most important outcrop of the ore is that at Iron Mountain, which is cut into two parts by Chugwater Creek, the larger part lying to the north of the creek and having a northwesterly strike. The ore projects as a black dam across the anorthosite, and forms the ridge of the hill for a distance of about 2 miles. The contact of ore and country rock is everywhere smooth and even slickensided and free of all transitions. The summit of the hill rises about 1,000 feet above the valleys. On the slope of the hill are two subordinate ore dikes. With the exception of the locality next described, the ore is free from all gangue minerals.

On the south side of Chugwater Creek, a short distance east of the main ore body, is a smaller dike about 15 feet wide which carries con-

^a Die Lagerstätten titanhaltigen Eisenerzes im Laramie Range, Wyoming, Vereinigten Staaten: February, 1905, pp. 71-80.

^b Petersson, W., *Geol. Fören Föreländ.*, vol. 15, 1893, p. 45.

^c Williams, G. H., *Am. Jour. Sci.*, March, 1887, p. 197.

siderable olivine. The olivine occurs irregularly, but is more abundant near the periphery of the dike. No change in the character of the anorthosite is noticeable at the contact, which is well exposed here.

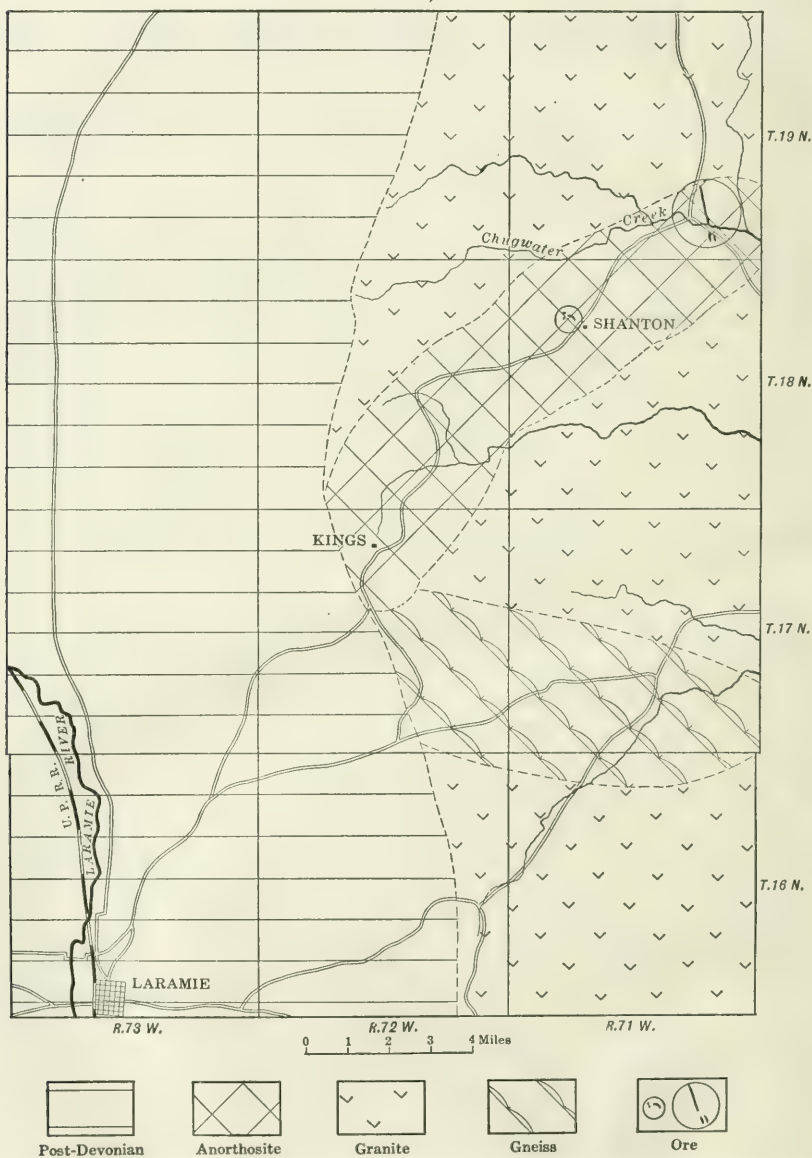


FIGURE 1.—Geological sketch of the region between Laramie and Chugwater Creek, Wyo. (after Kemp).

Though the titaniferous magnetites are usually looked upon as basic segregations, the manner of occurrence of this ore body establishes beyond doubt its intrusive character. It must be looked upon as a

dike. The occurrence of such an ore body is not as surprising as might seem at first thought. Titanium plays the same rôle in eruptive rocks as silica, and these ores have an average of 23 per cent TiO_2 . In other words, they are an iron titanate instead of ferromagnesian silicates.

The chemical composition of the anorthosites is likewise significant. They contain little besides silica, alumina, lime, and soda. In a normal rock we would also expect iron and magnesium and a small percentage of TiO_2 . If an original simple magma gave rise through differentiation to these two contrasting formations, which in their chemical relation are so abnormal, it was nothing less than exceptional. Therefore, it is not surprising that a titaniferous magnetite is found where the chief product is a ferromagnesian free anorthosite. Also a small iron and titanium content distributed through a large mass can through concentration bring about the formation of a very considerable ore body.

The deposit was also visited and described in 1906 by Ball.^a He gives some data not contained in the descriptions already discussed, and these are repeated here.

Iron Mountain is described as a rugged ridge 300 to 600 feet wide and $1\frac{1}{4}$ miles long, its exact location being given by Ball as in sections 22, 23, 26, and 27, T. 19 N., R. 71 W. He says further:

Besides this main body of the magnetic iron, minor masses occur in the pre-Cambrian rocks in a belt which is reported to extend from Horse Creek to Sibylee Creek, a distance of 20 miles. This belt, which courses a little east of north and west of south, is in places 5 miles wide. * * *

The greater portion of the main deposit passed into the hands of the Union Pacific Railroad as part of the land granted to it in 1862. In 1872 a wagon road was built to the deposit, prospectors rushed in, and the whole countryside was staked. In the following year a post office, Iron Mountain, was established at the base of the Iron Ridge, but was abandoned in 1874. Eight or ten years ago the Colorado Fuel & Iron Co. employed 15 teams for several months in hauling ore from the mountains to the railroad, where it was shipped to their smelters at Pueblo. The work was suddenly abandoned, however, although the same company is reported to have made a small shipment four years ago. In 1905 and 1906 the main ore body was visited by a number of surveying corps, and the Colorado Land & Iron Co. is said to have located claims between Chugwater and Sibylee Creek.

The pre-Cambrian complex near the large dike of Iron Mountain consists of three granular igneous rocks—an anorthosite, the iron ore, and a granite. The anorthosite is the oldest of these and is cut by dikes and lenticular masses of iron ore and granite. The relative ages of the iron ore and granite was not certainly determined, since exposures are poor where the two rocks are close together. All of the available evidence, however, indicates that the iron ore is older than the granite.

The mass of iron ore is an igneous dike $1\frac{1}{4}$ miles long and 40 to 300 feet wide, the greatest observed width being at the point where Chugwater Creek cuts through the mass. The dike trends east of north; most of it lies north of the creek. It widens and contracts rather abruptly throughout its course. Toward the north it gradually narrows and finally disappears, while 300 feet south of Chugwater Creek it narrows slightly and then abruptly ends. At several places it is almost cut in two by wedge-like masses of granite, but throughout practically its whole length it is bordered by

^a Ball, S. H., Titaniferous iron ore of Iron Mountain, Wyo. Contributions to Economic Geology: Bull. 315, U. S. Geol. Survey, 1907, pp. 206-212.

anorthosite. The contact between the anorthosite and the ore, where exposed, is sharp, neither rock having undergone important gradational changes. A second dike of iron ore is exposed 300 feet downstream (east) on the south side of Chugwater Creek; this dike varies in width from 6 to 20 feet and is clearly intrusive in the anorthosite, with which it has sharp contacts. About one-eighth of a mile southeast of the south end of the main mass is a third dike of iron ore in anorthosite. The trend of this dike, which is 300 feet long and from 10 to 30 feet wide, is approximately parallel to the main mass. Several small magnetite dikes that are from 10 to 50 feet long, and have maximum widths of 3 feet, lie east of this mass in parallel alignment.

The iron ore is a black, granular, holocrystalline igneous rock, with constituent grains varying from one-eighth to one-half inch in diameter. It has a metallic or sub-metallic luster. Changes in granularity occur in irregular masses or along well-defined parallel planes. In consequence of this distribution the rock has at some places an original gneissic structure. The greater portion of the iron is free from mechanical impurities, but biotite, olivine, and feldspar are sporadically distributed throughout its mass. Olivine is particularly abundant in portions of the small dike 300 feet east of the main mass. The iron ore is cut by rather closely spaced joints and by slickensided fracture planes. In consequence, the outcrop is angular, and its surface is littered with square blocks broken from the ore in place.

As seen under the microscope the ore in some specimens consists principally of titaniferous iron with a little spinel. Other thin sections show considerable olivine, while biotite and labradorite are present in many specimens and in a single section a crystal of what appears to be brown hornblende was noticed.

The writer considers the iron ore and the anorthosite differentiation products of a common magma, the iron ore having been intruded in the anorthosite after that rock had completely solidified.

The above-quoted abstracts of articles by Lindgren, Kemp, and Ball show that their views as to the nature of the deposit are essentially in accord. There are a few inconsistencies in details of description. To serve as a summary of this review, a brief description of the deposits follows, based principally on the writer's own observations.

IRON MOUNTAIN DEPOSITS.

Iron Mountain forms part of the eastern edge of a pre-Cambrian area cut off on the east by Paleozoic limestones and sandstones. The prevailing rocks of the pre-Cambrian area are gneisses and granites, and these have been intruded by a large mass of anorthosite, which has itself been intruded by granitic dikes. Iron Mountain is a ridge a little over a mile long with a direction a little west of north, and an altitude of about 1,000 feet. It is made up principally of anorthosite into which has been intruded a large mass of magnetic ore, which, on account of its greater resistance to erosion, forms the summit of the ridge. The width of the ore body varies considerably, ranging from 50 to 200 feet. The ridge of the mountain is not a straight line but consists of a series of knolls which correspond to the wide parts of the ore body, such places offering greater resistance than where the ore body is narrow. The southern part of the hill is cut through by Chugwater Creek, forming a steep gorge, in

the sides of which the ore body is well exposed. About 500 feet before reaching the creek the dike takes a sudden turn of 200 yards to the west and then resumes its normal strike. Plate X, A, shows the part of the dike south of the offset as seen from the south side of Chugwater Creek. The hill in the right background is the main ridge of Iron Mountain. The plate shows clearly the manner in which the ore projects above the adjacent rock. About 400 feet south of the creek the ore body suddenly terminates.

In thin section the anorthosite is a medium to coarse grained rock consisting almost entirely of plagioclase feldspar. As accessory constituents it contains small amounts of magnetite, biotite, and a monoclinic pyroxene. All of these minerals have been somewhat altered, giving rise to the usual secondary minerals. A little south of the center of Iron Mountain are two intrusions of a biotite granite which seemingly cut the ore body. This rock in thin section is seen to consist of microcline and quartz, with considerable orthoclase and biotite.

At the same part of the hill where the granitic intrusions occur, are three smaller ore bodies on the west slope. One of these is only 200 feet below the summit, and the others nearer the foot of the hill.

On the south side of Chugwater Creek, 300 feet east of the main dike, is a smaller dike which is characterized by an unusually large amount of olivine and plagioclase, and shows exceptionally well the contact of ore and anorthosite. Plate X, B, is a view of the contact here exposed. The rock on the right is normal anorthosite, which abuts directly against the iron ore without showing any change whatever. That the ore body is not a segregation in situ but an intruded body is evident from this exposure. On the left side of the plate a part of the dike is shown. Against the contact is a band of ore about 1 foot wide that contains such a large quantity of olivine that the olivine in places makes up half of the bulk. Next to this is an extremely crumbly layer about 2 feet wide. This contains, in addition to olivine, considerable plagioclase of the same gray color characteristic of the anorthosite. This part is a granular aggregate of magnetite, olivine, and feldspar, though the magnetite and olivine tend to be more intimately associated with each other than either is with the feldspar. Following this is another band consisting of magnetite and olivine, and then solid ore containing no more gangue than the main ore body. A thin section of the olivine-rich ore from this locality consisted principally of magnetite and olivine. In the magnetite were a few dark-green spinels and two small flakes of biotite. The biotite occurs intimately associated with spinel, the spinel almost surrounding and thus separating them from the magnetite. In general the ore of the main ore body is a

medium to coarse grained magnetite containing little visible gangue. Locally, olivine is rather abundant, especially on the northern end of the mountain. Biotite is also widely distributed, but not in great amounts. On polished surfaces considerable spinel is seen disseminated through the magnetite, and in thin sections this is still more prominent. The crystals attain a diameter of as much as 1 mm. In one slide containing more olivine than the normal amount several small crystals of hornblende occurred in the olivine. A white crust of calcium carbonate frequently coats the ore, especially in crevices. In the northwest corner of the large outcrop on the highest point of Iron Mountain is a layer from 1 to 2 inches thick which cuts across the ore body at an angle parallel to the hill slope. This is an intimate mixture of fragments of ore and bunches of chlorite in a matrix of the white calcium carbonate.

The following results of analyses of the ore from Iron Mountain and from Shanton ranch are available:

Results of analyses of Iron Mountain ore.

Con- stituent.	1	2	3	4	5	6	7	8	9	10
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
TiO ₂	23.49	23.32	23.18	49.47	22.43	21.75	19.47	21.85	21.08	19.98
SiO ₂	.76		2.15		1.21					
Fe ₂ O ₃	45.03		48.97		47.21					
FeO.....	17.96		24.55		25.80					
Al ₂ O ₃	3.98									
Cr ₂ O ₃	2.45									
Mn ₂ O ₃	1.53									
CaO.....	1.11									
MgO.....	1.55									
ZnO.....	.47									
P.....	Trace.									
S.....	1.44		.03		1.14					
	99.78		98.88		97.79					
Fe.....	45.49	50.83	53.33	34.29	51.72	52.31	54.48	51.93	51.50	52.98

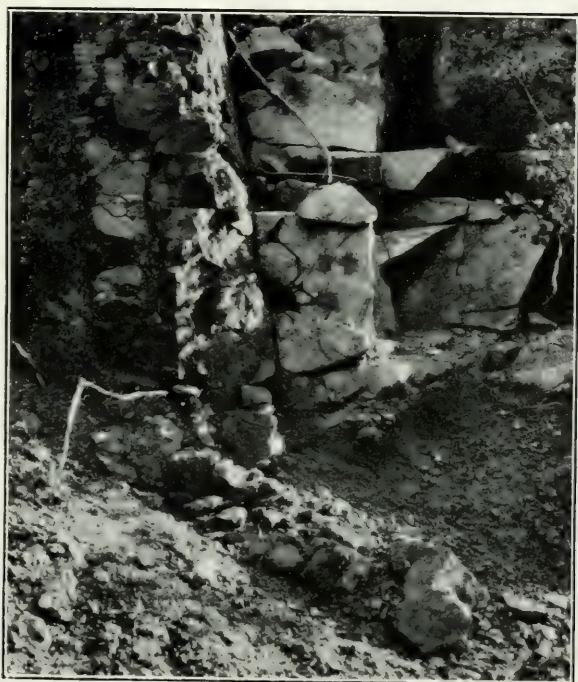
• Insoluble.

Analyses 1, 2, 3, 4, and 5 have been cited in the foregoing pages, 1 being from Hayden's report, 2, 3, and 4 from Hague's, and 5 from Bulletin 14 of the Wyoming experiment station. Kemp suggests that 4 may be from the Shanton ranch occurrence. Analyses 6, 7, 8, 9, and 10 were computed from analyses of concentrates and tailings made by A. C. Fieldner, of the Bureau of Mines. They are analyses of specimens of ore that were studied metallographically. The first three were from Iron Mountain and the last two from Shanton ranch.

With the exception of analysis 4, the analyses show considerable uniformity in the composition of the ore. Analysis 4 contains iron and titanium in almost the exact ratio in which they are present in ilmenite, but the metallographic study has failed to reveal any ores of that composition at either Iron Mountain or Shanton ranch. It



A. ORE ON IRON MOUNTAIN, WYO.



B. CONTACT OF ORE AND ANORTHOSITE, IRON MOUNTAIN, WYO.

is more likely, therefore, that the sample was obtained from some other small deposit running unusually high in titanium, and it will be left out of consideration. The average composition of the ores from both occurrences is, then, 51.38 per cent Fe and 21.84 per cent TiO_2 . The titanium content is somewhat higher than the average for titaniferous magnetites. The average composition is equivalent to an ore composed of 49.84 per cent magnetite and 41.5 per cent ilmenite. With the exception of analysis 1, all the analyses are so incomplete that little further comment can be made on them. The high percentages of sulphur in analyses 1 and 5 are noteworthy, as is the unusual percentage of ZnO in 1, and the presence of several per cent of Cr_2O_3 .

The contact between the ore and the wall rock is not usually exposed, but wherever the relations can be seen it is sharply defined. There is no transition from ore to wall rock. The anorthosite in contact with the ore shows the same features that characterize the anorthosite at a distance from the contact. The ore also is the same at the contact with the anorthosite as farther within the ore body. That the deposit is not a magmatic segregation in situ is evident, and the relations are such as to establish beyond doubt the intrusive character of the ore. The relations existing between anorthosite and deposits of titaniferous iron ores in other regions as in Canada, the Adirondacks, Minnesota, and elsewhere, make it most probable that the anorthosite and iron ore came from the same parent magma. Deep-seated magmatic segregation took place. The anorthosite was intruded, and subsequently the iron ore body was intruded into it in the same manner in which the igneous dikes were intruded. The Iron Mountain deposit is therefore the analogue in basic igneous rocks of the large deposits in acidic igneous rocks, of which Kiruna, in Sweden, is the most striking example.

SHANTON RANCH DEPOSITS.

At Shanton ranch are several smaller dikes of similar character to the Iron Mountain deposit. They are situated in sec. 8 or 9, T. 18 N., R. 71 W. The geological conditions here are similar to those at Iron Mountain. The deposit lies within the anorthosite belt, which here is also cut by granitic dikes, one of which is exposed within 50 yards of the ore. The deposits occur in the midst of a comparatively level stretch of land above which they rise as small hills, the summits of which are formed by the iron ore. The relative position of the ore body is shown in figure 2. Outcrops A, B, and C are probably parts of the same ore body, though the exposures are not continuous. Outcrops D and E are smaller isolated occurrences. The width of these varies from 20 to 80 feet, the maximum width

being attained by outcrop C. The relations of the ore to wall rock are the same as at Iron Mountain, and the same explanation of their origin holds.

Results of analyses of the ores have been given in the table on page 120. From these it is seen that they are essentially of the same

composition as the Iron Mountain ores. Macroscopically the ores from the two localities are also identical, except that no olivine or feldspar was seen at this locality and only a few flakes of biotite. In almost all specimens any evidence of gangue minerals is lacking. On polished surfaces, however, the presence of spinel is revealed.

METALLOGRAPHIC DESCRIPTION OF ORE.

Etched polished sections of the ore show considerable variation. The ilmenite forms from one-tenth to one-third of the surface of the sections, types of which are shown in Plate II, *D*, and Plate IX, *B*. The ilmenite grains are nearly all about 0.25 mm. in diameter, and some areas of ilmenite have a surface of 104 sq. mm. The shape of the grains varies from approximately equidimen-

sional to distinctly elongate. The elongate grains tend to occur in between the grains of magnetite, and may become as narrow as 0.1 mm. Some of the broader elongated grains fray out rapidly on the ends, as shown in Plate XI, *A*. Though usually following the out-

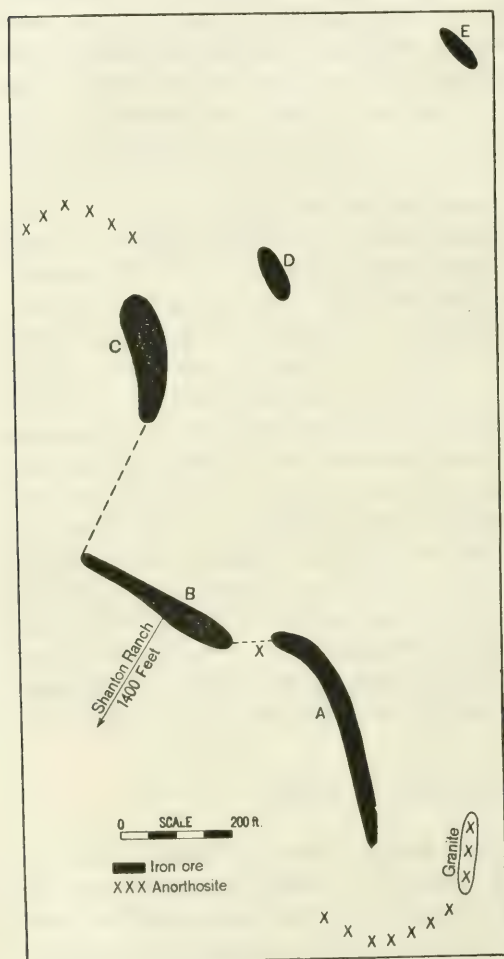
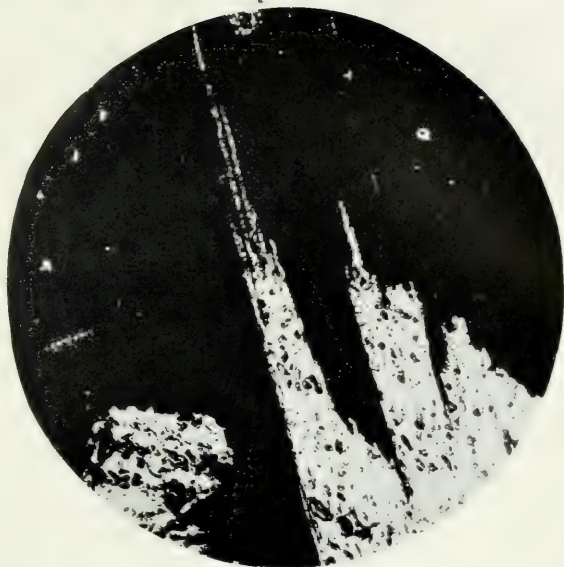
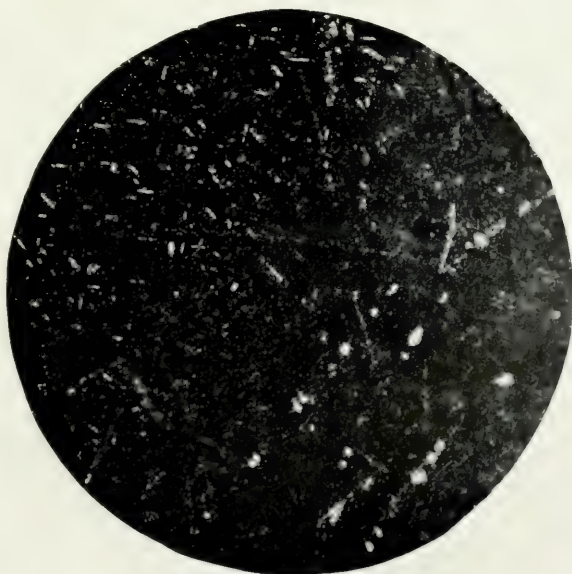


FIGURE 2.—Ore outcrops at Shanton ranch, Wyoming.



A. SHANTON RANCH, WYO., ORE. ($\times 60$.)



B. IRON MOUNTAIN, WYO., ORE. ($\times 60$.)

line of the magnetite grains, some of the narrow ilmenite grains take on a regular arrangement within the magnetite.

Except for a few sections in which olivine was present in considerable amount, little gangue is visible. The most prominent mineral besides the olivine is spinel. Though not present in large amount, it occurs throughout the ore in small particles. The most abundant inclusions of ilmenite in the magnetite show on the polished section as dashes and dots. The long lamellæ forming the regular linear network are almost entirely lacking, and their place is taken by the dashes which have an average length of 0.1 mm.

The dashes occur in some cases widely spaced, giving an open structure, as in a part of Plate XI, *B*; in other cases they are very closely crowded, giving a dense network effect as in Plate XII, *A*. This finally becomes so close that the effect of a somewhat continuous surface of ilmenite is produced, such as has already been described in the case of Minnesota and other ores.

The dots are in two sizes, a larger series having a diameter of about $\frac{1}{25}$ to $\frac{1}{30}$ mm. The larger dots occur irregularly distributed, or linearly along outlines of magnetite and rectilinearly parallel to cleavage directions. The irregular distribution of both large and small dots is shown in Plate XII, *B*, and XIII, *A*. The latter also shows the development of the ilmenite lamellæ. The rectilinear arrangement of the larger dots is shown in a part of Plate XI, *B*.

The minute dots occur in irregular swarms and become so minute in places as to be scarcely discernible. A great deal of the magnetite does not show a dull-black surface, but has a gray, mottled appearance. This is doubtless due to just such intergrowths, which have become too minute to be resolved with a microscope. It is shown below that a large percentage of the titanium of the ores occurs within the magnetite, a fact in accordance with the above explanation of the mottled appearance of the magnetite.

A further interesting feature noted is the abundant development of the intersecting lamellæ along certain lines in the magnetite, which seem to be the outlines of the magnetite grains. In such cases the parts of the magnetite at a distance from these lines are practically free from ilmenite lamellæ. This is illustrated in Plate XIII, *B*.

POSSIBILITIES OF UTILIZATION.

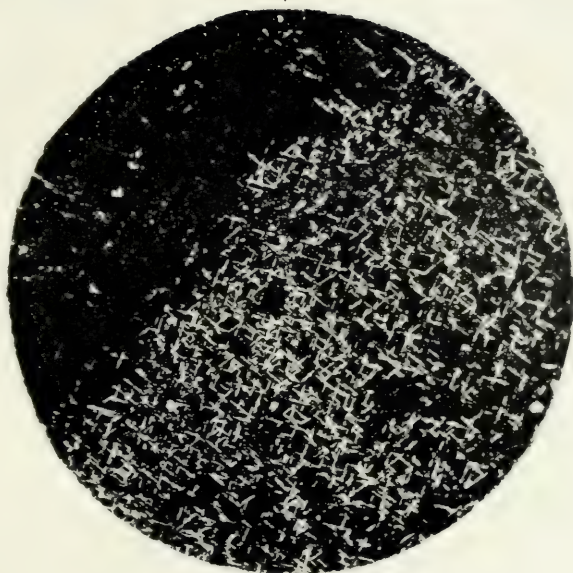
Five specimens of the ore were crushed and separated with a hand magnet. The first three were from Iron Mountain and the last two from Shanton ranch. The results follow:

Results of magnetic separation of Iron Mountain and Shanton ranch ore.

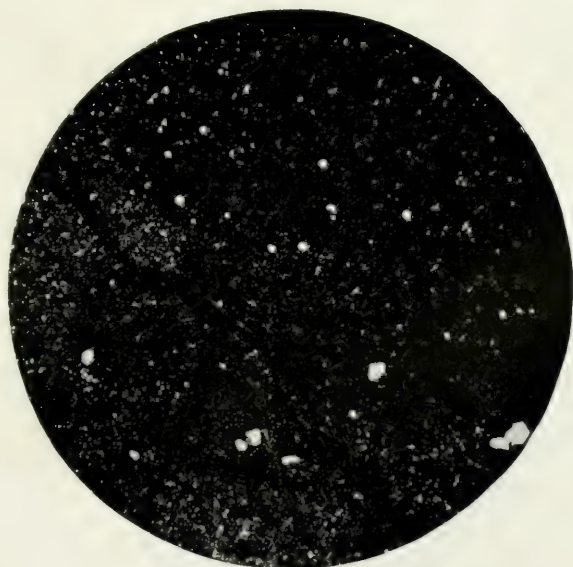
	Un-screened ore.	Ore through 50-mesh, over 100-mesh.			Ore through screen finer than 100-mesh.	
		Magnetic.	Nonmagnetic.	Proportion through screen.	Magnetic.	Proportion through screen.
Proportion.....	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	52.31	84.2	15.8	48.8	83.6	51.2
TiO ₂	21.75	56.75	28.74	.....	76.75	.....
		18.30	40.12		17.25	
Proportion.....		77.7	22.3	46.3	76	55.7
Fe.....	54.48	60.76	32.61		61.97	
TiO ₂	19.47	12.58	43.47		10.32	
Proportion.....		87.3	12.7	46.6	86.5	53.4
Fe.....	51.93	55.35	28.43		55.44	
TiO ₂	21.85	20.03	34.33		20.03	
Proportion.....		84.7	15.3	48.0	82.2	52.0
Fe.....	51.50	55.05	31.83		55.63	
TiO ₂	21.08	17.85	38.93		17.85	
Proportion.....		84.1	15.9	47.5	78.6	52.5
Fe.....	52.98	56.93	31.96		57.30	
TiO ₂	19.98	17.22	34.58		16.72	

Of these five samples the average Fe content is 52.64 per cent, and the average TiO₂ content, 20.83 per cent. Of the 50-100 mesh concentrate the average Fe content is 56.97 per cent, and the average TiO₂ content, 17.20 per cent. Of the concentrates finer than 100-mesh the average Fe content is 57.42 per cent, and the average TiO₂ content, 16.43 per cent. The average composition of the 50-100 mesh tailings is Fe 30.71 per cent, TiO₂ 38.29 per cent. This corresponds to a composition of the original ore of 52.56 per cent magnetite and 39.58 per cent ilmenite; of the 50-100 mesh concentrates, 62.05 per cent magnetite and 32.68 per cent ilmenite; of the concentrates that passed through a 100-mesh screen, 63.41 per cent magnetite and 31.22 per cent ilmenite; of the 50-100 mesh tailings, 72.75 per cent ilmenite and 5.40 per cent magnetite. It is again seen that there is little advantage in grinding finer than 50-mesh. This is what one could predict from the size of the ilmenite grains, as practically all are larger than the size passing through a 50-mesh screen, and the ilmenite intergrowths in the magnetite are too minute to be separated by the 100-mesh crushing.

The disappointing feature is the small amount of titanium removed. A careful study of the ore, however, reveals the cause of this. Polished sections of the five specimens of ore subjected to magnetic



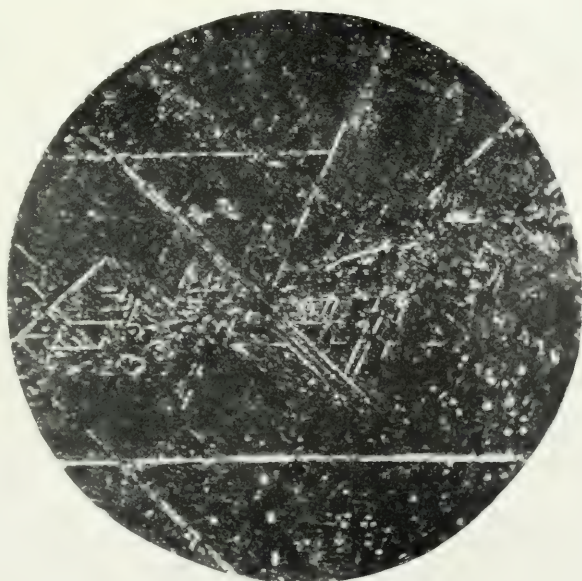
A. IRON MOUNTAIN, WYO., ORE. (X 60.)



B. SHANTON RANCH, WYO., ORE. (X 60.)



A. IRON MOUNTAIN, WYO., ORE. ($\times 60$.)



B. IRON MOUNTAIN, WYO., ORE. ($\times 60$.)

concentration were carefully measured, and it was found that ilmenite grains of separable size formed 15.3 per cent of the surface. If we calculate the titanium in the tailings in terms of ilmenite, we find the average by weight to be 12.1 per cent of the original ore. Allowing for the difference in specific gravity between magnetite and ilmenite, this is equivalent to 12.7 per cent of the original surface. In other words, 15.3 per cent of ilmenite was measured, and 12.7 per cent was separated, which is equivalent to a separation of 83 per cent of all ilmenite present in a separable condition. When the crude method of making the separation is taken into account, the result is all that could be expected.

It was shown above that 39.58 per cent of the original ore consisted of ilmenite, and that an equivalent of 12.1 per cent of ilmenite was removed. Consequently 27.48 per cent of ilmenite remained in the concentrates, which is equivalent to 69.4 per cent of the original ilmenite content of the ore. Hence the result of the separation tests was to separate 30.6 per cent of the titanium and to leave 69.4 per cent in the concentrates. It was further shown that by measurement 15.3 per cent of the ore was present in a separable condition. This was equivalent to 14.56 per cent by weight, or 36.8 per cent of the total ilmenite content of the ore; that is, only 36.8 per cent of the titanium of the ore is in a separable condition. The remaining 63.2 per cent of the titanium is so intimately intergrown and included in the magnetite as to make separation impossible. Even if a perfect separation of all ilmenite grains of separable size were obtained, there would still remain a concentrate with 13.2 per cent TiO_2 and 7.96 per cent Ti.

It is therefore apparent that it is impossible to make from this ore a concentrate low in titanium. However, the deposits are most attractive as to size and ease of mining.

COLORADO.

CARIBOU HILL.

Caribou Hill is located in Boulder County, Colo., 3 miles northwest of Cardinal Station, on the Colorado & Northwestern Railroad. The deposits of titaniferous iron ore occur on the northeastern and southeastern slopes of the hill, close to the old town of Caribou, in the Caribou or Grand Island district, where once were rich silver mines. This camp is now almost deserted and only a remnant of the town remains.

Putnam^a collected two samples here in 1880, the analyses of which are given below, and describes the deposit as follows:

A mass of titaniferous magnetite occurs in Caribou Hill, near the Caribou and other silver mines, in Boulder County. Caribou is 20 miles from Boulder, near the Conti-

^a Tenth Census, vol. 15, 1886, p. 476.

mental Divide. Its elevation above tide is 9,900 feet. Two small openings were made at the western end of the outcrop some years since, and a little ore was taken out and teamed to Boyd's smelter at Boulder. The pits are 8 to 10 feet deep and 6 to 8 feet wide. The ore exposed in them and seen on the dump varies greatly in richness, the mass being made up of little seams of rich, compact magnetite, lying in a siliceous magnetic rock. The outcrop extends along the crest of the hill, and is about 400 feet in length. The north side of the hill is completely covered with float ore. All the ore is very magnetic, and exhibits polarity to so marked a degree that the dip of the needle changes from $+90^{\circ}$ (north end down) to -50° (south end down) in the distance of 10 paces. There is undoubtedly a large amount of iron ore in the hill, but it is probable that the rich ore is too irregularly distributed through the rocks to permit of its being economically mined, even if other circumstances were favorable.

Chauvenet^a spoke of the deposit in 1886 as a vein of black magnetite, and gave an analysis of the ore which is cited below. In 1890 he made the following mention^b of the occurrence:

Beginning with Boulder County, we have the vein in Archean rock already mentioned, which is found on Caribou Hill, close to many rich silver veins, though not itself forming part of the system of veins which carry the precious metals. This vein powerfully affects the compass in its vicinity and is called a deposit of magnetite, though, as far as analysis is concerned, it might be named ilmenite, since it contains the unusual amount of 36 per cent of titanitic acid. Its percentage of iron is from 36 to 38. The ore is compact, jet black, and, of course, worthless as iron ore.

Kemp^c also refers to the deposit briefly, saying that beyond establishing the character of the ore little has been accomplished and no determinations of the wall rock have been recorded.

A detailed account of the deposit has recently been published by Jennings.^d

GENERAL FIELD RELATIONS.

The deposit lies in the northeastern corner of the Central City quadrangle, which has recently been mapped by E. S. Bastin and J. M. Hill, of the United States Geological Survey. A detailed description of the geology and the ore deposits of this district is now in the course of preparation by the Survey and only a brief sketch of the geology is given here.

The district is within the belt of pre-Cambrian granites and gneisses forming the Front Range. These rocks have been intruded by numerous dikes ranging in composition from acidic to extremely basic. On Caribou Hill are several intrusions of basic material, and it is within these that the ore occurs. The most important one is the dike on the northeast slope of the hill, which can be traced for over 1,500 feet. It begins at a point 500 yards west of Caribou and

^a Chauvenet, Regis, Notes on iron prospects in northern Colorado: *Bien Rept. of the Colo. State Sch. of Mines*, 1886, p. 16.

^b Chauvenet, Regis, the iron resources of Colorado: *Trans. Am. Inst. Min. Eng.*, vol. 18, 1890, p. 267.

^c Kemp, J. F., A brief review of the titaniferous magnetites: *Sch. of Mines Quart.*, 1899, p. 335.

^d Jennings, E. P., A titaniferous iron-ore deposit in Boulder County, Colo.: *Bull. Am. Inst. Min. Eng.*, October, 1912, pp. 1045-1056.

runs up the hill slope in a southeasterly direction for about 400 feet, where it bends sharply to the east and continues for about 1,000 feet to the edge of Caribou. A second intrusion, having more of a stock shape, occurs on the southeast slope of the hill, half a mile southwest of Caribou. A third smaller outcrop occurs near the top of the hill about 100 yards southeast of the summit. These rocks show considerable local variations, but are essentially pyroxenitic in character. Associated with the pyroxene in places is feldspar and biotite. The texture ranges from that of a coarse pyroxenite to a very fine-grained rock.

THE ORE DEPOSITS.

Some magnetite occurs as an accessory constituent of the basic rocks, and this becomes segregated into richer pockets, forming a medium-grade ore. But even in the ore-bearing parts of the rock the composition is not uniform. It is rather a rock rich in magnetite with numerous stringers and veinlets of almost pure magnetite. The magnetite is highly magnetic and much of it is natural lodestone. These stringers of pure ore never exceed 6 inches in thickness and seldom measure more than an inch or two. They may form such a network within the leaner rock as to constitute a medium-grade ore. Such ore bodies do not reach a width of more than a foot or two or a length of more than a few feet. The ore in the pits and trenches that have been made along the western end of the dike northwest of Caribou consists of a series of closely crowded lenses of that character. The dike has a width of 50 to 100 feet or over, but only a small part consists of ore of even this grade. The ore in the other two occurrences is still leaner and there is still less of it. Thin sections of the ore show that it consists essentially of the ore minerals and pyroxene, the latter ranging in composition from diopside to augite. The pyroxene is frequently altered to serpentine, and in part to hornblende. Some biotite is also usually present. Inclusions of dark-green spinel in the magnetite are common.

The following analyses of the ore have been published. Analyses 1 and 2 are taken from the Tenth Census Report and analysis 3 from Chauvenet. Analysis 4 is calculated from the more detailed analysis by Jennings, which is also given in full.

Results of analyses of Caribou iron ore.

Constituent.	1	2	3	4
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	59.04	35.35	36.93	50.97
SiO ₂			1.16	9.60
TiO ₂	Present.	Present.	36.76	4.48
P.....	.017	.022	.04	

Mineralogical composition of medium-grade ore from northwest dike.

[Analyst, E. P. Jennings.]

	Per cent.
Ilmenite.....	8. 50
Magnetite.....	67. 25
Apatite.....	. 18
Spinel.....	6. 70
Diopside.....	16. 89
H ₂ O at 105°.....	. 51

METALLOGRAPHIC DESCRIPTION OF ORE.

A metallographic study of the ore shows little of interest. The richer veinlets consist of medium-grained aggregates of magnetite and ilmenite with a little gangue. The ilmenite is far less abundant than the magnetite and occurs in smaller grains, in many places as small particles filling interstices between the magnetite and the gangue grains. The leaner ore, which grades over into the country rock, contains scattered grains of magnetite and ilmenite, with the femic minerals in excess.

Intergrowths of ilmenite in the magnetite are not abundant. Most frequently they consist of dots and small particles scattered irregularly through the magnetite. Regular intergrowths of tabular ilmenite in the magnetite are not numerous. Altogether, the quantity of ilmenite seen in polished surfaces would not lead one to expect the high titanium content given by Chauvenet in his analysis, a conclusion that is corroborated by the analysis by Jennings presented above.

POSSIBILITIES OF UTILIZING ORE.

Titaniferous magnetite occurs in small pyroxenitic intrusions on Caribou Hill. The best of the ore is only medium grade and the ore lenses are very small. On account of its small size the deposit can never have any economic value.

IRON MOUNTAIN.

Iron Mountain is situated in the southern part of Fremont County, about 12 miles southwest of Cañon City, and 15 miles north of Silver Cliff. It lies on a branch of Pine Creek, which is itself tributary to Grape Creek, and the locality is often referred to as Grape Creek. More exactly, it is 3½ miles east of the western edge and 1 mile north of the 38° 20' line of the Cañon City topographic sheet.

Though the deposit has been visited several times, there is little information to be had in regard to it. This is doubtless the deposit referred to by F. M. Endlich in 1873.^a He says: "A short distance up Grape Creek Cañon a deposit of magnetic iron ore occurs, which

^a Hayden, F. V., Seventh Annual Report of the United States Geological and Geographic Survey of the Territories, 1873, p. 333.

is being worked at present." This was probably about the beginning of mining operations here, as Putnam^a states that a United States patent for the land was obtained in 1872. During this period the ore was hauled by wagon to Cañon City by freighters on their return trips to that point. Shortly before 1880 a branch line of the Denver & Rio Grande Railroad was built up Grape Creek from Cañon City to Silver Cliff. This passed within 4½ miles of the deposit, and preliminary surveys were made for a branch line up Pine Creek to the deposit, but the line was never built; and in 1888, after a series of washouts, the Silver Cliff line was abandoned. The deposit was worked at several points, but none of the pits are large, the average being about 50 feet long, 10 to 15 feet wide, and 10 to 15 feet deep. Consequently the total amount of ore mined was not great.

The most complete account of the deposit is given by Putnam,^b and in his report a number of analyses of the ore are included.

In 1885 Chauvenet,^c referring to these ores, says:

The ore is a magnetite, not very siliceous, but containing from 10 to 15 per cent of titanitic acid. Its use, even in relatively small quantity, was found extremely troublesome, and was limited to such a proportion that the entire mixture of ores charged should contain but 1 per cent of the impurity. Even at this low figure the working of the furnace was retarded. This ore yielded 45 per cent of iron and sometimes more, but the workings have been practically abandoned.

Again, in 1890, he says:^d

In Fremont County is the mine known as the Grape Creek. The ore is titaniferous, showing a very steady average of about 14 per cent of titanitic acid. Its iron runs about 48 per cent. It is no longer used in the blast furnace, but is useful as "fix" in the puddling mill. The deposit is a large one, and it is a pity that its character prevents its more extensive use.

Kemp's account^e is based chiefly on Putnam's, but in addition he determined a specimen of gray granitoid rock in a collection of the titaniferous ores at Columbia University to be olivine gabbro. This is the first and only information we have as to the character of the rock associated with the ore.

GENERAL FIELD RELATIONS.

The prevailing rocks of the region are granites and gneisses. These have been cut by numerous dikes, prominent among which are pyroxenite. Besides the dikes, they have also been intruded by a large mass of gabbro. The greater part of this mass forms a high hill north of the ore deposits, which is known as Iron Mountain.

^a Putnam, B. T., Tenth Census, vol. 15, 1886, p. 472.

^b Op. cit., pp. 272-276.

^c Chauvenet, Regis, Preliminary notes on the iron resources of Colorado: Ann. Rept. of the Colo. State Sch. of Mines, 1885, p. 16.

^d Chauvenet, Regis, The iron resources of Colorado: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 270.

^e Kemp, J. F., A brief review of the titaniferous magnetites: Sch. of Mines Quart., 1899, pp. 333-334.

The gabbro continues southward across a low flat spur of Iron Mountain and two small hills separated by dry arroyas. It is on this spur and the two hills that the ore deposits occur. The ore-bearing part of the gabbro takes on a more feldspathic character than that composing Iron Mountain, and in places grades over to a true anorthosite.

The gabbro is likewise cut by dikes, the most common of which are hornblende syenite with accessory zircon and magnetite. At the south end of the spur of Iron Mountain are several dikes of a dioritic rock. This location is marked A on the map constituting figure 3. One of the dikes cuts through both the gabbro and an ore segregation in it. The groundmass of the rock is a coarse granular aggregate of plagioclase feldspars of about the composition of oligoclase. Zircon occurs as an accessory constituent, and in one part of a slide is a swarm of minute isotropic grains which seem to be spinels. Green pyroxene and amphibole are prominent constituents of the rock. The crystals of these minerals are usually larger than those of the feldspar, and some of the hornblende prisms attain a length of 3 cm. and a diameter of 0.5 cm.

As stated above the gabbro varies in character from a typical olivine gabbro to one in which the ferromagnesian minerals become accessory and which approaches a typical anorthosite in composition. The most abundant ferromagnesian mineral in the gabbro is augite; less abundant but prominent is olivine. Magnetite, with numerous inclusions of green spinel, and a little biotite and hornblende are also present. The anorthositic phases contain the same minerals in subordinate amounts. A slide of this rock shows the olivine surrounded by rims of hornblende so that it usually does not come in contact with the feldspar.

THE ORE DEPOSITS.

The first hill south of the spur from Iron Mountain affords the most promising showing of ore, and it is here that most of the openings were made. This hill is 800 feet long, 500 feet wide, and 60 feet high. The locations of the principal ore bodies in it were determined by Putnam by means of a magnetic survey, and are shown in figure 3, reproduced from his map. These ore bodies are exposed at several points both in natural exposures and in the old ore pits, and the relations of the ore to the wall rock are well shown.

The distinction between what is ore and what is wall rock can generally be sharply drawn. The wall rock may be anorthosite or it may be a gabbro rich in ore minerals; the ore may be a rich magnetic ore with little gangue, or it may be a lean ore carrying large percentages of the common constituents of the adjacent wall rock. But no matter how closely the two may approach each other in composition, there

hardly ever exists what one would call a gradual transition. The change from wall rock to ore is so rapid that one has no difficulty in fixing a contact.

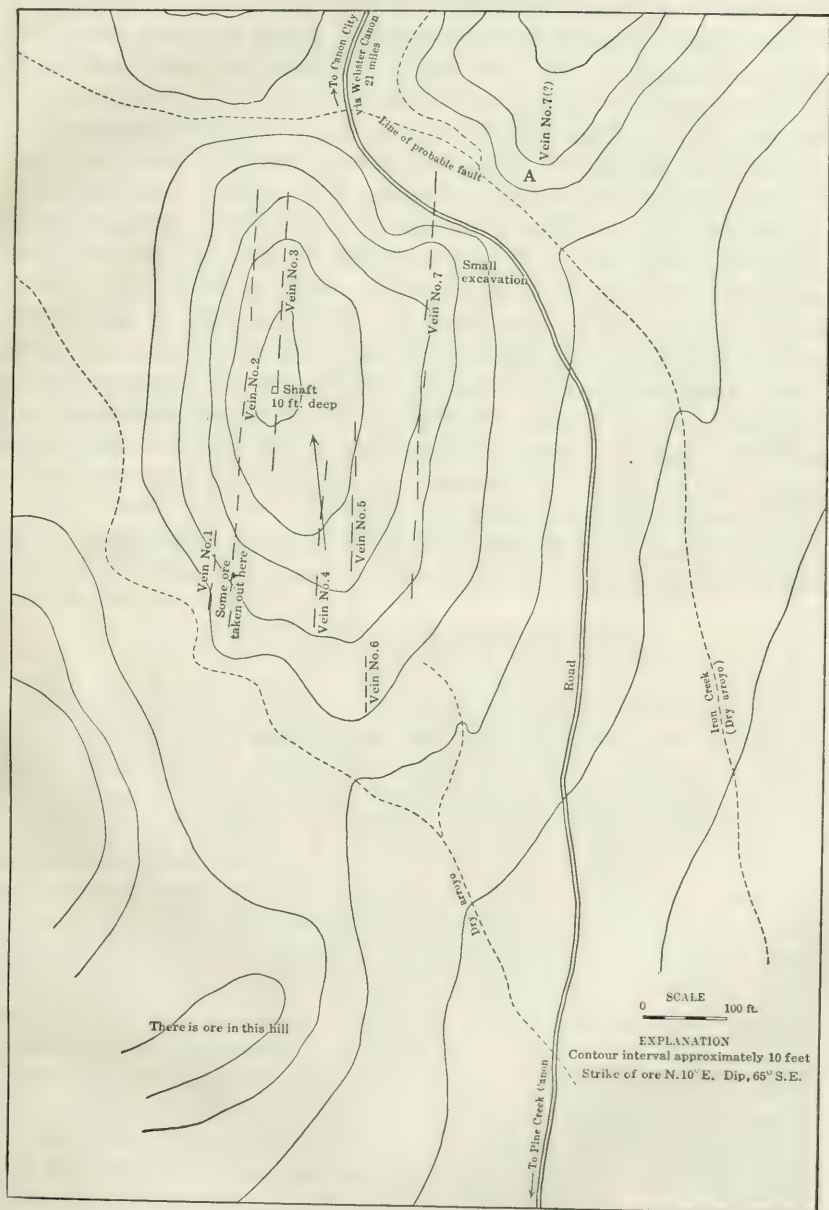


FIGURE 3.—Map of Iron Mountain, Colo. [From Tenth Census report.]

The width of the ore bodies ranges from about 10 to 50 feet, and does not average more than 25 feet. Their length can not be determined on account of lack of exposure. Whether those indicated on

Putnam's map (fig. 3) are continuous or represent zones of ore lenses is an open question. The latter supposition is the more probable.

The ore itself is rather uniform in composition and appearance. It is a compact aggregate of magnetite and ilmenite, on fresh fractures of which the ilmenite can be recognized by its higher luster. The gangue minerals are the constituent minerals of the gabbro. In some specimens the gangue is very prominent; in general, however, the ore is of good grade. The most characteristic mineral of the gangue is the feldspar. It has a tabular habit, and tends to a sub-parallel arrangement, which gives to the ore a striking diabasic appearance. The similarity of this ore to some of the Minnesota ore has already been mentioned. Plate VIII, *C*, shows a specimen of the ore in which the white feldspar crystals are plainly visible against the dark background of the ore minerals. A thin section of the ore consisted of nearly three-fourths magnetite in which are abundant inclusions of dark-green spinel. The most prominent gangue minerals were the lath-shaped feldspars. Olivine was less abundant and biotite only sparingly present. Along the boundary of the feldspar and olivine against the magnetite is a narrow rim of a yellowish-brown mineral which seems to be hornblende.

Several analyses of the ore have been made and they show a very uniform composition. The analyses are tabulated below:

Results of analyses of Iron Mountain ores.

Constituent.	1	2	3	4	5	6
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	48.89	48.18	46.61	48.85	46.05	47.01
TiO ₂	11.99	12.92	11.61	12.73	13.84	14.86
P.....	.025	.026	.037	.011	.040	.039

Constituent.	7	8	9	10	11
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fe.....	47.42	49.35	43.4	48.79	51.96
TiO ₂	13.04	14.00	10.0		14.5
P.....	.026			Trace.	

Constituent.	8	9	10
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Silica.....	8.60	18.60	2.75
Alumina.....	4.00	7.00	7.70
Lime.....	1.60	1.30	None.
Magnesia.....	2.30	1.60	3.20
Titanic acid.....	14.00	10.00	
Peroxide of iron.....	70.50	62.00	
Magnetic oxide of iron.....			67.76
Sulphuric acid.....			Trace.
Phosphoric acid.....			Trace.
Oxide of manganese.....			Trace.
	101.00	100.50	

Analyses 1 to 7 are taken from Putnam's report, analyses 1 to 5 representing samples taken from the ore bodies indicated on figure 3 by the numbers 2, 3, 6, 3, 4, respectively. The sources of samples represented by analyses 6 and 7 are not given. The samples represented by analyses 8 and 9 were collected by M. Chaper, and the analyses made at the School of Mines, Paris. M. Chaper, of the Geological Society of France, visited the deposit in 1875, and extracts of his report together with the analyses were published in 1877-78. The analyses as here presented are taken from Putnam's report, in which they are cited. The sample represented by analysis 8 is described as a "compact titaniferous magnetite with feldspathic gangue"; the sample represented by analysis 9 is described as "an oxidized iron sand, forming the bed of Iron Creek for several miles above Iron Mountain. A portion of the iron exists in the state of protoxide, which is all converted into peroxide, whereby the increase in weight results." Analysis 10 was made in 1871 by Charles S. Hinchman and was quoted by Putnam. Analysis 11 was calculated from analyses of concentrates and tailings made by A. C. Fieldner, of the Bureau of Mines.

The average composition of the ore is shown to be 47.86 per cent Fe, 12.95 per cent TiO_2 , and the phosphorus content considerably below the Bessemer limit. The titanium content is about the average for titaniferous magnetite.

METALLOGRAPHIC DESCRIPTION OF ORE.

All the polished sections of the ores that were studied are much alike. On all of these the gangue constitutes less than one-fourth of the surface and averages about one-eighth. Ilmenite grains seldom exceed 10 per cent of the surface, and the average is below 10 per cent. Manifestly, the magnetite must contain a considerable part of the titanium.

A conspicuous feature of the magnetite is the almost complete absence of the large intersecting lamellæ of ilmenite. The most common ilmenite intergrowths are dots, which occur in great numbers. Though every intermediate size occurs, they tend to be of two orders of magnitude. The most abundant are extremely minute dots, examples of which have already been shown in the case of other deposits. (See Pl. XII, *B*, and Pl. XIII.) The larger series have a diameter which may be expressed in hundredths of a millimeter, and in places become as great as 0.1 mm. Both sizes of dots may be, and usually are, present in the same specimen. Pl. XIV, *A*, shows the large dots both irregularly distributed and in linear arrangement.

On some surfaces are seen extremely delicate networks of closely spaced short lamellæ in the midst of which are dots of the larger size. The effect is that of a minute network upon which the dots

have been superimposed. This is illustrated in Plate XIV, *B*. Such a network in many places grades over into a more minute network until finally the intersecting structure can no longer be recognized even under high power. The transition is gradual enough to make certain that the disappearance is not due to the discontinuance of the network, but to the fact that it becomes so delicate as not to be discernible.

Another method of intergrowths is the occurrence of well-formed laths of ilmenite. These range from 1 to 2 mm. in length and may have a width of as much as 0.2 mm., though usually much less. This feature is shown only in a few places. It reminds one of the intergrowths of the North Carolina ore shown in Plate VII, *A*. In this case, however, the laths are smaller and much more regularly formed.

POSSIBILITIES OF UTILIZING ORE.

The structure of the ore revealed on polished surfaces is such as to make impossible the elimination of any considerable percentage of the titanium by means of magnetic concentration. Not more than one-third of the titanium occurs in grains large enough to be isolated when crushed to 100-mesh. The following results of a test on a specimen of the ore are even more disappointing than one would have expected:

Results of magnetic separation of Iron Mountain ore.

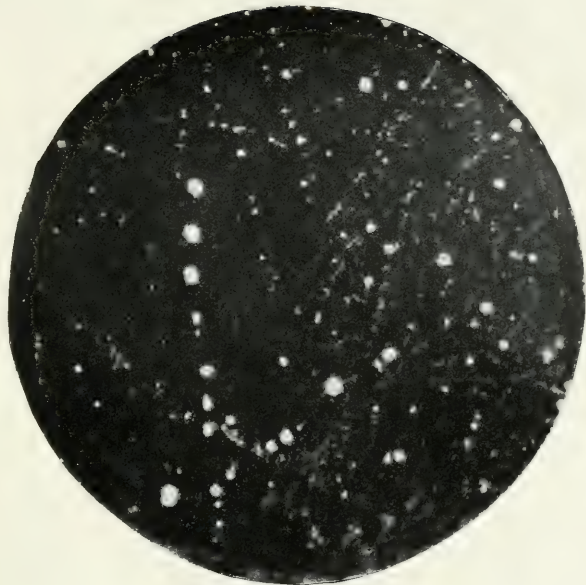
	Ore.	Ore that passed through 50-100 mesh screen. ^a		Ore that passed through screen finer than 100-mesh. ^b
		Mag-netic.	Nonmag-netic.	Mag-netic.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Quantity.....		86	14	80.4
Fe.....	51.96	56.93	21.42	57.77
TiO ₂	14.5	13.5	20.97	13.1

^a 46 per cent.

^b 54 per cent.

Here as in other cases the separation is little better in the more finely crushed ore, owing to the fact that the ilmenite grains are nearly all larger than a 50-mesh opening and the intergrowths in the magnetite are nearly all smaller than a 100-mesh opening.

The ores have about the average composition of titaniferous magnetites, but the titanium is intergrown with the magnetite in such a manner as to make possible only a very incomplete separation of the two. Hence their utilization depends entirely upon the possibility of using ores containing 14 per cent TiO₂. But even in such an event



A. IRON MOUNTAIN, COLO., ORE. ($\times 60$.)



B. IRON MOUNTAIN, COLO., ORE. ($\times 60$.)

the deposit is not very promising. The individual ore bodies are not large and the total tonnage not great; also, the expense of securing proper transportation facilities would be heavy. Consequently this occurrence can not be looked upon as an important ore reserve.

CEBOLLA CREEK.

The Cebolla district is located on the east side of Cebolla Creek, south of Powderhorn, in the southern part of Gunnison County. It lies about 9 miles east of the Lake City branch of the Denver & Rio Grande Railroad, but is best reached by a stage line from Iola, on the Denver & Rio Grande narrow-gage line which lies 15 miles to the north.

The occurrence of titaniferous magnetite in this region has been known for some years, but no description of the deposit has ever been published.

J. K. Hallowell ^a visited the deposit in 1883, and said of it:

The Cebolla iron deposit is a peculiar formation unto itself. I was asked regarding its geology. I had to weaken; I never saw anything like it or read of anything similar. There is iron enough, over a mile square of it, apparently overlaid by trachyte at one time. The country rock is granite. The ore is heavy black magnetite, of fair grade of iron, but carrying, as I was afterwards informed, * * * too much titanium to be practically available in iron manufacture.

Chauvenet ^b in a report on the iron resources of Gunnison County in 1887 makes the following mention of it:

We come next to a region known as the "Cebolla" district, situated near White Earth Creek (usually called Cebolla Creek) and at an average distance of about 26 miles from Gunnison City. This district lies very close to a proposed extension of the Denver & Rio Grande Railroad to Lake City, Hinsdale County.

An immense ledge of titaniferous iron ore exists here, but little need be said of it. Samples taken from it vary greatly in their percentage of this objectionable material, the lowest I have ever analyzed yielding 9.38 per cent and the highest 36 per cent. This last was rather to be classed as "ilmenite" than as iron ore. This deposit is enormous in extent and is well worth exploitation with a view to ascertaining whether in parts or at depth it will not yield a product lower in titanium than any yet discovered. At present it must be condemned as unfit for smelting, at least by itself.

Two years later Chauvenet again refers to the deposit as follows:^c

Next, as a curiosity, not as a commercially valuable mine, I would name the Cebolla Creek titanium deposit. No one knows how the ore will hold out here, but as it can be developed in many places for some miles it will last, in all likelihood, far longer than there is any use for it. It contains from 9 to 36 per cent of titanic acid. We have all read in our textbooks on chemistry that titanium is a "rare" metal. I do not think I risk much in saying that this is an inexhaustible stock of it.

^a Hallowell, J. K., Gunnison, Colorado's Bonanza County: Colo. Mus. App. Geol., 1883, p. 106.

^b Chauvenet, Regis, Iron resources of Gunnison County: Ann. Rept. State Sch. of Mines of Colo., 1887, p. 18.

^c Chauvenet, Regis, The iron resources of Colorado: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 272.

In 1896, Arthur Lakes ^a described deposits of nontitaniferous iron ore which occur in the immediate vicinity of the titaniferous iron, but made only a brief reference to the latter. He examined the small opening close to the road, directly opposite the Cebolla Hot Springs, and described the ore as "gray massive iron" which is "mingled with streaks of brown mica and a green, somewhat asbestiferous-looking mineral, which may be hornblende or pyroxene."

Kemp ^b refers to the deposit and comments on the lack of information in regard to the ore or wall rock.

In the summer of 1905 or 1906 the district was visited by Van Hise and Leith, ^c and is classed by them genetically with the Iron Springs district of Utah; that is, as a contact metamorphic deposit.

The above information in regard to this district, though meager, was of such a character as to excite considerable interest from a scientific point of view. No titaniferous magnetites of contact metamorphic origin are known to the author. Krusch ^d cites the absence of titanium as one of the characteristics of these ores, and Beyschlag, Krusch, and Vogt ^e state that experience up to the present has been that these ores are characterized by an almost complete absence of titanitic acid, with an occasional trace.

Here was seemingly a highly titaniferous contact metamorphic magnetite deposit, and the author's examination of the same showed that such actually was the case for a part of the deposit. A detailed account of the geological features of the deposit has recently been published by him ^f and the geological discussion in this report is restricted to a summary of that account.

GENERAL FIELD RELATIONS.

The Cebolla district lies within a region of pre-Cambrian rocks consisting mostly of granites and gneisses. In the midst of these rocks is an area of basic igneous rocks, limestone, and rhyolitic lavas. It is in association with the basic igneous rocks and the limestone that the titaniferous iron ores occur. The basic rock contains numerous small segregations of ore. It has intruded a part of the limestone in a most intricate manner, producing products of contact metamorphism and the deposition of contact metamorphic iron ores.

^a Lakes, Arthur, Iron and manganese; The great Cebolla River deposits: Coll. Eng. and Metal Miner., 1896, pp. 267-268.

^b Kemp, J. F., A brief review of the titaniferous magnetites: Sch. of Mines Quart., 1899, p. 335.

^c Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, 1908, pp. 92, 93.

^d Krusch, P., Die Untersuchung und Bewertung von Erzlagerstätten, 1907, p. 179.

^e Beyschlag, Krusch, Vogt, Die Lagerstätten der nutzbaren Mineralien und Gesteine, vol. 1, 1909, p. 351.

^f Singewald, J. T., jr., The iron-ore deposits of the Cebolla district, Gunnison County, Colo.: Econ. Geol., 1912, pp. 560-573.

ORE DEPOSITS.

MAGMATIC SEGREGATIONS.

The basic igneous rock has undergone considerable differentiation, and shows rapid variation from place to place, especially in the ore-bearing area. To the north of the ore-bearing area it consists of a dark, greenish, fine-grained rock, in which locally considerable chalcopyrite is disseminated. The leaching of this has given rise to green, copper stain in crevices of the rock, and at one such point some prospecting has been done. Within the ore-bearing area the rock is somewhat coarser grained, and especially in association with the ores becomes very coarse grained. In general the coarse-grained varieties are feldspar poor or free, though typical feldspar-rich gabbro does occur. Most of these coarse varieties consist of coarsely crystalline aggregates of pyroxene, biotite, and ore in all possible ratios.

The richer ores consist of aggregates of titaniferous magnetite and bunches of dark-brown mica which reach several centimeters in diameter. In such specimens pyroxenes are not abundant. They grade over, however, into leaner ores in which the pyroxenes are more abundant, until a rock results that consists almost entirely of pyroxene. The ores are not entirely confined to these coarse rocks, but also occur as veinlets and stringers in the adjacent fine-grained rocks. These ores were prospected and worked to a slight extent about 30 years ago by a Mr. Crooks, of Lake City, who hauled some to the smelter located there at that time. Their titaniferous character was soon discovered and further shipments were refused by the smelter. The most extensive openings were made in a draw 1 mile northeast of the Hot Springs. Another opening 50 feet long, was made just above the main road in the valley due east of the Hot Springs. Besides these, numerous smaller openings have been made, especially where the intrusions in the limestone occur. The ores throughout the area show the same features, both as to their mineralogical associations and their geological occurrence. There is no evidence of the occurrence of any large ore bodies, but rather of a large number of very small ore segregations. No analyses of the ores were made, but the metallographic study of the ores corroborates the high percentages of titanium given by Chauvenet. In almost all specimens examined the ilmenite was far in excess of the magnetite.

The composition of the ores, their mineralogical association, and their manner of occurrence establish beyond doubt their genetic position. They are magmatic segregations of titaniferous magnetites in a basic igneous rock.

CONTACT METAMORPHIC ORES.

Petrographically the area within which the limestone has been intruded by the basic rock affords a complete gradation from the basic igneous rock to a pure-white, coarsely granular marble. In some places the igneous rock has resorbed some of the limestone, so that calcite occurs in it as a primary constituent. At other places occurs limestone in which large mica flakes are abundantly disseminated. Elsewhere, typical products of contact metamorphism of limestone have been formed. The transitions are so rapid that one can pass from one extreme to the other within a few paces. The effect is that of a limestone mass that has been intricately intruded by the igneous. Sufficient time was not available to determine whether the intrusion took place in the form of a large number of distinct dikes, or in the form of irregular stocks. The complex is the least resistant of the rocks of the region, and hence has not afforded many pronounced outcrops.

The igneous rock is the same as that described above, and associated with it are small ore segregations of the character described.

The most interesting feature of this complex is the occurrence of small deposits of contact metamorphic ore. The product of contact metamorphism is usually a light-green, compact rock. In thin section, this rock is seen to be made up of calcite, augite, garnet, and, less abundantly, of zoisite and vesuvianite. The relative abundance of these minerals varies greatly in different specimens. In many places there occurs, as phenocrysts as much as 5 centimeters long, a dark augite with purplish tinge. Less abundant than this light-green, dense rock is a somewhat coarser dark rock which contains a larger percentage of yellow to brown garnets and deep-colored augite. Within the contact metamorphic rock are numerous pockets and nests of magnetite. These pockets of ore, though small, contain very little gangue. They are usually separated from the surrounding light-green rock by a narrow zone of the darker coarse-grained mixture of garnet and augite. A study of polished sections of this ore, one of which is reproduced in Plate II, *F*, showed that it consists of both ilmenite and magnetite; and, though seemingly not as abundant in amount as in the magmatic segregations, the ilmenite forms a considerable part of the ore. From a scientific standpoint, this is the most important and striking feature of the district—the occurrence of highly titaniferous iron ore of contact metamorphic origin.

REPLACEMENT ORES.

A third type of ore in the district is a replacement of the limestone, which, as it is not titaniferous, is of no particular interest in this connection, though the ultimate source of the iron was probably the same in all three types.

METALLOGRAPHIC DESCRIPTION OF THE ORE.

Though the individual segregations are small, the ore itself is rather high grade, and polished sections contain little gangue. The average percentage of gangue on a number of polished surfaces of the ore scarcely exceeds 15 per cent. The ore grains average from 2 to 5 mm. In some cases they reach as much as 10 mm. and few are smaller than 0.5 mm. The ratio of ilmenite to magnetite varies between wide limits in different specimens but is uniformly great, indicating an ore high in titanium. No analyses were made of this ore, but Chauvenet gives the range of TiO_2 between 9 and 36 per cent. In only a few sections did the magnetite exceed the ilmenite; and in some cases the ilmenite made up more than three-fourths of the surface. A very common relation of ilmenite to magnetite is that illustrated in Plate II, *E*. The two minerals, magnetite and ilmenite, are of so nearly the same hardness that no differences in relief are brought out by the ordinary amount of polishing. Two specimens (Pl. II, *E* and *F*) of this ore, however, which were polished longer than usual show a slight difference. The highly polished surface of the ilmenite has been cut back a little so that the magnetite stands out in slight relief.

The inclusions of ilmenite in the magnetite present several features of interest. One of the larger features is the segregation of irregular elongated particles of ilmenite about the periphery of ilmenite grains. These particles are not in direct contact with the ilmenite, but are separated from it by a narrow zone of magnetite free from ilmenite. This is well shown at the right end of Plate II, *E*. The effect is different from that described in the case of the Adirondack ore and illustrated in Plate VI, *B*. In this case the elongated particles of ilmenite are arranged parallel to the outline of the large grains, whereas in the case of the Adirondack ore they tend to orient themselves at right angles to them. Hence the broad, somewhat continuous bands formed by the coalescing of the ilmenite particles in the Adirondack ore are not found in the Colorado ore.

Many of the sections showed a tendency for the ilmenite to occur as a thin layer between the individual magnetite grains, so that their outlines are marked by a bright line of ilmenite, as has been illustrated in Plate IV, *A*. In places, instead of the simple film of ilmenite, there is a marked development of lamellæ along the outline as is seen in Plate XV, *B*. Very similar intergrowths were observed in some of the Iron Mountain, Wyo., ores, and are shown in Plate XIII, *B*.

A network of large intersecting lamellæ, as in Plate XV, *B*, is not very common, but is in places unusually well developed, the lamellæ attaining a length of 2 mm. In one section, characterized

by an unusually heavy network, the thickness of the lamellæ was 0.07 mm. In most cases the network is poorly developed; the lamellæ occur in only a part of the magnetite crystals, only one series being prominent, or they are extremely short and faint. The short lamellæ are particularly well illustrated in a section of the contact metamorphic ore reproduced in Plate XVI, A.

The most common form of ilmenite inclusion is as minute dots. Many of the magnetite grains are swarming full of such minute particles of ilmenite. As a rule they seem to be distributed without any regularity, but in places they tend to have a linear arrangement. This may even become sufficiently pronounced to give the effect of a triangular network of dotted lines. In some cases the dots are slightly elongated, and the network made still more striking. It would seem therefore that the swarms of minute dots represent the incipient stage in the formation of the network of intersecting ilmenite lamellæ. The linear arrangement of the dots on the polished surfaces represents the orientation of the dots into planes parallel to the octahedral faces of the crystallizing magnetite. The elongation of the dots is caused by the coalescing of several dots. As this process continues small lamellæ of ilmenite are formed in intersecting series of parallel plates.

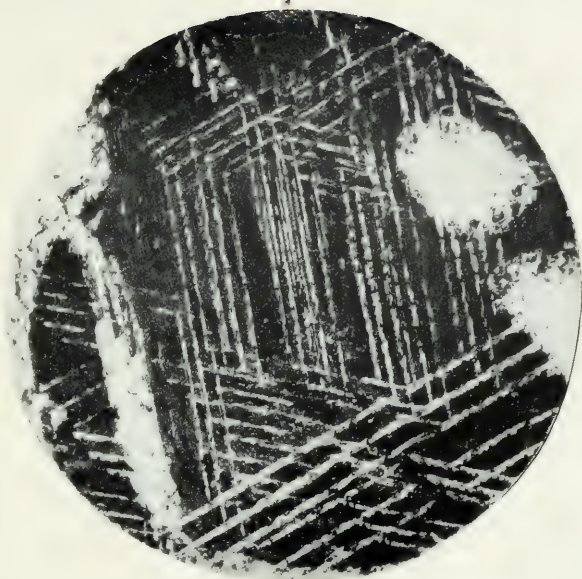
POSSIBILITIES OF UTILIZING ORE.

The possibilities of these ores are not very promising. Although a considerable tonnage of ore doubtless exists, it occurs in the form of countless small segregations, so that large-scale operations are impossible. Magnetic concentration to obtain a concentrate low in titanium is not feasible, because ilmenite forms more than 50 per cent of the ore, so that the percentage of magnetite concentrate obtained would be very small. The inaccessible location of the deposit is also a serious drawback.

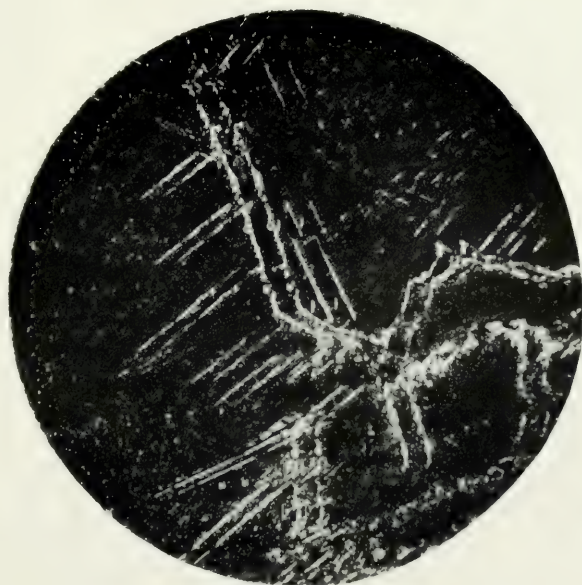
RÉSUMÉ.

The evolution of the modern blast furnace has taken place in such a direction as to make the utilization of titaniferous iron ores impracticable. Notwithstanding numerous experiments that have been conducted with a view to discovering a furnace charge that will make the use of these ores practicable from the standpoint of furnace operation and economy, there is to-day no hopeful feeling in regard to the possibilities of smelting these ores in the blast furnace. On the other hand, the introduction of the electric furnace holds out a new hope for the direct reduction of the titaniferous ores.

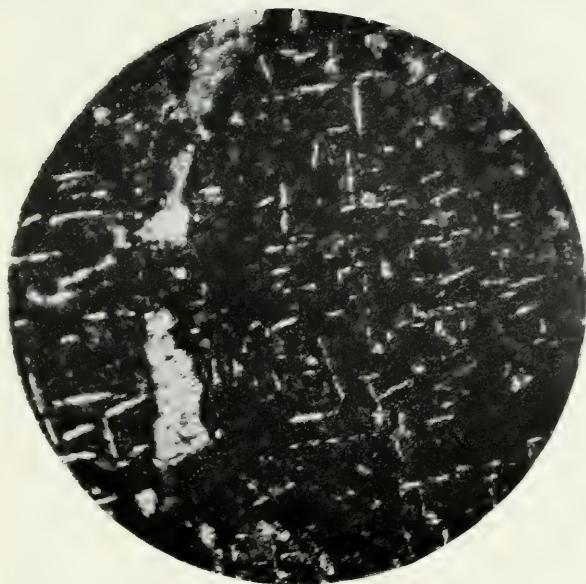
The results of magnetic-separation experiments conducted with these ores are very promising in some cases and extremely disap-



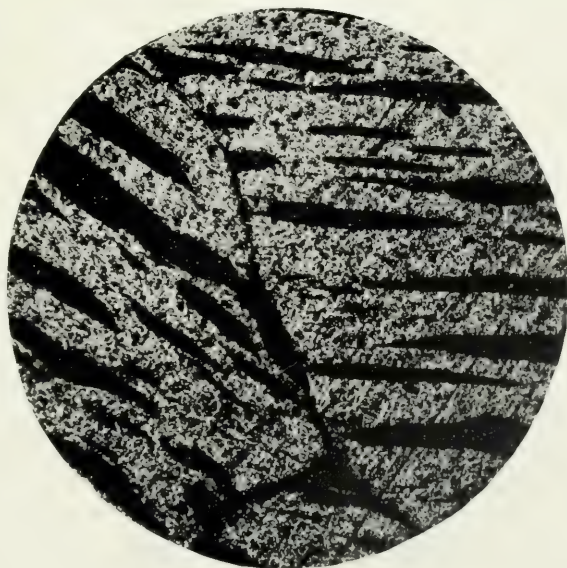
A. CEBOLLA CREEK, COLO., ORE. ($\times 60$.)



B. CEBOLLA CREEK, COLO., ORE. ($\times 60$.)



A. CEBOLLA CREEK, COLO., ORE. (X 60.)



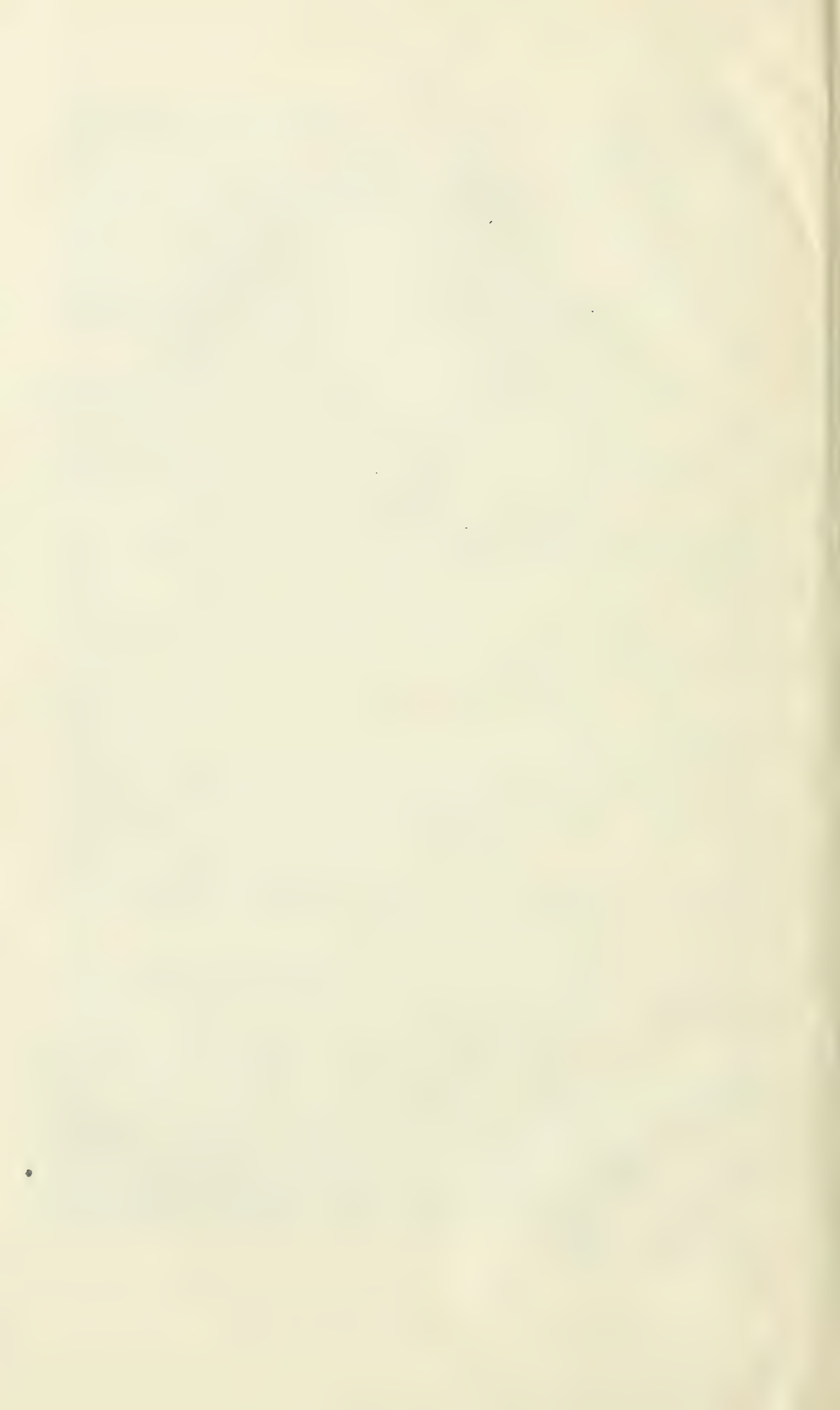
B. RIVER CHALOUPE, CANADA, ORE. (X 60.)

pointing in others. No rule of general application can be formulated as to the behavior of the ores. Some deposits are very amenable to magnetic separation, and yield concentrates that require the admixture of only a small proportion of nontitaniferous ores to make a satisfactory ore mixture. Other deposits are less amenable and yield concentrates that would have to be mixed with three or four parts of nontitaniferous ores for furnace use. There are many other deposits in which the percentage of titanium separable in this way is extremely small, so that the utilization of such ores seems to depend on the discovery of a process that will make their use feasible.

The cause of the difference in behavior of the ores toward magnetic separation is revealed in their microstructure which is readily studied by the metallographic method. This method of investigation shows that the titanium occurs in these ores in the form of ilmenite grains in about the same order of magnitude as the magnetite grains, as ilmenite inclusions and intergrowths of microscopic size in the magnetite, and as an integral part of the magnetite molecule itself. The titanium occurring in the first form (as ilmenite grains) is readily separable by means of magnetic concentration, except in the finest grained ores with which the degree of crushing required would make such concentration impracticable. The titanium occurring in the two latter forms is inseparable by mechanical means. The percentages of titanium occurring in these different forms varies greatly in the different ores, and, consequently, every case must be tested for itself. A metallographic study of the ores of any deposit will at once decide the question of the amenability of the deposit to magnetic separation.

As regards chemical composition, except for their titanium content, the ores are very desirable. The coarser-grained ores are usually high grade in their natural condition, whereas a magnetic separation of the leaner ores yields a high-grade concentrate, with the deleterious constituents at a minimum.

As the iron industry at present demands large deposits of definite extent, the outlook for most of the deposits of titaniferous iron ore in the United States is not promising. As a rule the deposits are relatively small and of irregular extent and distribution. Further, they are lean to medium grade, and inaccessibly situated as regards transportation facilities. In other words, to put the deposits on a producing basis would require a heavy initial outlay of capital, which the size and irregularity of occurrence does not warrant. There are, however, the two large, high-grade deposits of Sanford Hill, N. Y., and Iron Mountain, Wyo., which are so readily workable that, despite their titaniferous character, their utilization within a few years seems certain.



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